THE GEOLOGY OF CAPE ANN, MASSACHUSETTS,

BY

NATHANIEL SOUTHGATE SHALER.

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LETTER OF TRANSMITTAL.

United States Geological Survey,
Atlantic Coast Division,
Cambridge, Mass., June 20, 1888.

Sir: I herewith transmit to you the manuscript of a report on the surface and under Geology of the Island of Cape Ann and the neighboring parts of the Massachusetts shore. Although I have long had this work in contemplation and accomplished a small part of the task more than twenty years ago, by far the larger part of the field observations embodied in this memoir have been made by my assistant, Mr. Ralph S. Tarr. All the detailed observations on the dikes and joint planes and on the petrography of the district are his. In these parts of the work I have supplied only the general project and certain details concerning the method of presentation. In the petrographic work we have had the assistance of Dr. J. E. Wolff, assistant geologist of the Survey.

I am indebted to Messrs. George Bridge Leighton and John L. Gardner, jr., for their services in obtaining photographs from which all the illustrations of this report have been prepared.

Very respectfully, your obedient servant,

N. S. Shaler,
Geologist in Charge.

Hon. J. W. Powell,
Director U. S. Geological Survey, Washington, D. C.

THE GEOLOGY OF CAPE ANN, MASSACHUSETTS.

By N. S. Shaler.

NATURE AND OBJECTS OF THIS REPORT.

The island of Cape Ann and the neighboring portion of the mainland of Massachusetts form a remarkable salient at the northern extremity of Massachusetts Bay. The topographic individuality of this area and its general relations to the shore line of New England make it an attractive field for inquiry. Although it is proposed in the end to assemble in a general report the information gained in the study of the Atlantic coast line, it seems desirable from time to time to set forth the more important of these results in the form of detached memoirs. It will be a number of years before it will be possible to prepare a final report, and in the mean time by separate publications, the more important results obtained during the progress of the inquiry can be placed in the hands of other students of this interesting geological field.

I propose to set forth in the following pages what has been ascertained concerning the following points: First, the general structure of the district in question, and next, the superficial geology of this field under the following heads, viz: the distribution of the glacial drift, the amount of erosion during the last ice period, and the action of the sea upon the shores; afterwards I shall take up the structure and nature of the bed rocks, the variation in the character of the hornblendic granitites which compose the region, the various dike stones which intersect it, the character, origin and effect of the joint planes and the quarry rifts of the rocks, and, lastly, the relations of the region to the anticlinal axis of which it forms a part.

The field included in this inquiry at first sight appears to present little of geological interest; it has received hardly any attention from the geologists who have worked in eastern Massachusetts. This neglect is due to the fact that the geologic structure of the region is relatively simple. As will be seen from the geological map accompanying this report, the bed rocks are composed altogether of granitites and associated intrusions of an igneous nature. The absence of distinctly stratified deposits gives a uniform aspect to its structure and appears at first sight to afford little promise of important results to geological inquiry. Despite the disadvantage arising from

the lack of variety, this region affords certain peculiar advantages to the student for the prosecution of various inquiries. The general deforested condition of the island of Cape Ann, a feature which is shared in part by the mainland division of the area included in this report, enables the observer to note certain peculiarities in the distribution of the drift which are often obscured by forests in other parts of this region. The extensive shore line and the thoroughness with which the rocks near it have been stripped of their original covering by the action of the sea make it possible to observe the details of structure of the rocks along a section which has a length of more than thirty miles. (See Pls. XXXII–XXXV.) As will be seen hereafter in the body of this report, we are able from a study of this section to determine in a satisfactory manner many points concerning the structure of the rocks. The extensive quarries which exist also favor the prosecution of several inquiries.

These favoring features made it seem desirable to undertake on this ground a careful study as to the distribution of dikes in a mass of crystalline rocks, which, as we shall see hereafter, originally constituted the foundations of a great anticline. The field also seemed advantageous for a careful study of joint phenomena in their relation to the dikes, and to the strains which we may assume to have been developed in the formation of the anticlinal ridge. In this connection it also seemed well to undertake some inquiry into the nature of the rift or natural splitting planes which are availed of by the quarrymen in the separation of blocks of the granite from their bed. I am not aware that any of these inquiries have ever been prosecuted in the manner in which they are considered in this report. Lastly, the peculiar composition of this shore in relation to the sea makes it possible to study the effect of ocean waves of great magnitude on rocks which, though generally hard, vary much in the resistance which they offer to the impact of the waves. No other point on our coast line affords such opportunities for this inquiry as Cape Ann. The considerable extent to which this promontory projects into the open sea and the absence of reefs or other barriers between it and the wide ocean, together with the deep water which extends seaward from the shore, expose it to more powerful surges than assail most other parts of our rock-bound coast. As will be seen in the section of this report which deals with the problem of marine action since the close of the glacial period, we learn much from studying here the action of the sea.

The promontory of Cape Ann projects about twelve miles from the general line of the shore. It is composed of two sections, an outer part, made up of the main island which receives the name of the cape, and a few small islets all having a core of bed rock more or less enveloped with detrital materials, and an inner section which, though much cut up by deep indentations of the sea, is not completely sepa-

CLIFFS NEAR LOBLOLLY COVE, SHOWING POST-GLACIAL MARINE EROSION, FORMING DISTINCT BENCH ALONG THE SHORE.

rated from the mainland. The outer portion of the promontory, to which we give the name of the Island of Cape Ann, was at the close of the glacial period and for some time thereafter completely separated from the mainland by the tolerably deep inlet which bears the name of Squam River. The considerable amounts of detrital matter borne in by the sea which have accumulated in the Gloucester harbor have in recent times closed the southern extremity of this fiord by a beach wall. Behind this wall the usual growth of marine marshes still further effected the closure, so that when the country was settled by Europeans there was an isthmus of marsh and beach having a width of about one-third of a mile which separated the waters of Gloucester harbor from those of Squam River. This barrier has been artificially cut through so as to permit the passage of boats, and thus the original insulated character of the cape has been restored.

The fact has been stated that the whole of this salient is much exposed to the action of the ocean surges. An inspection of the soundings given on Coast Survey Chart No. 109 shows that they rapidly and somewhat uniformly descend from the shore line towards deep water. The ten-fathom line is generally found at a distance not exceeding a mile from the shore, and at several places, particularly near Eastern Point and near the northern promontories of the island, it comes to within less than half a mile of the shore. The contouring line drawn on the soundings of twenty fathoms is at no point more than two and a half miles from the shore of the main island and generally is not much more than one and a half miles from its margin. Beyond the twenty-fathom line the bottom descends steadily to the depth of from twenty-five to fifty fathoms, these depths being generally attained at distances of not more than four miles from the coast. A comparison of the position of our shore with reference to deep water will make it plain that these features of the bottom favor the action of ocean waves on this part of the coast, and therefore fit the shore to be the seat of special inquiry on this point.

GENERAL GEOGRAPHIC AND GEOLOGIC RELATIONS OF THE CAPE ANN DISTRICT.

The island of Cape Ann is composed altogether of three classes of rocks—an original field of the nature formerly known as syenites, rocks now designated by petrographers under the name of hornblendic granitites, which occasionally approach a true granitic character. These granitites, as we shall afterwards show, probably represent a succession of dislocatory movements partially due to true injections and in part to faulting, the variations in the character of the crystalline matter being due in the main to these displacements.

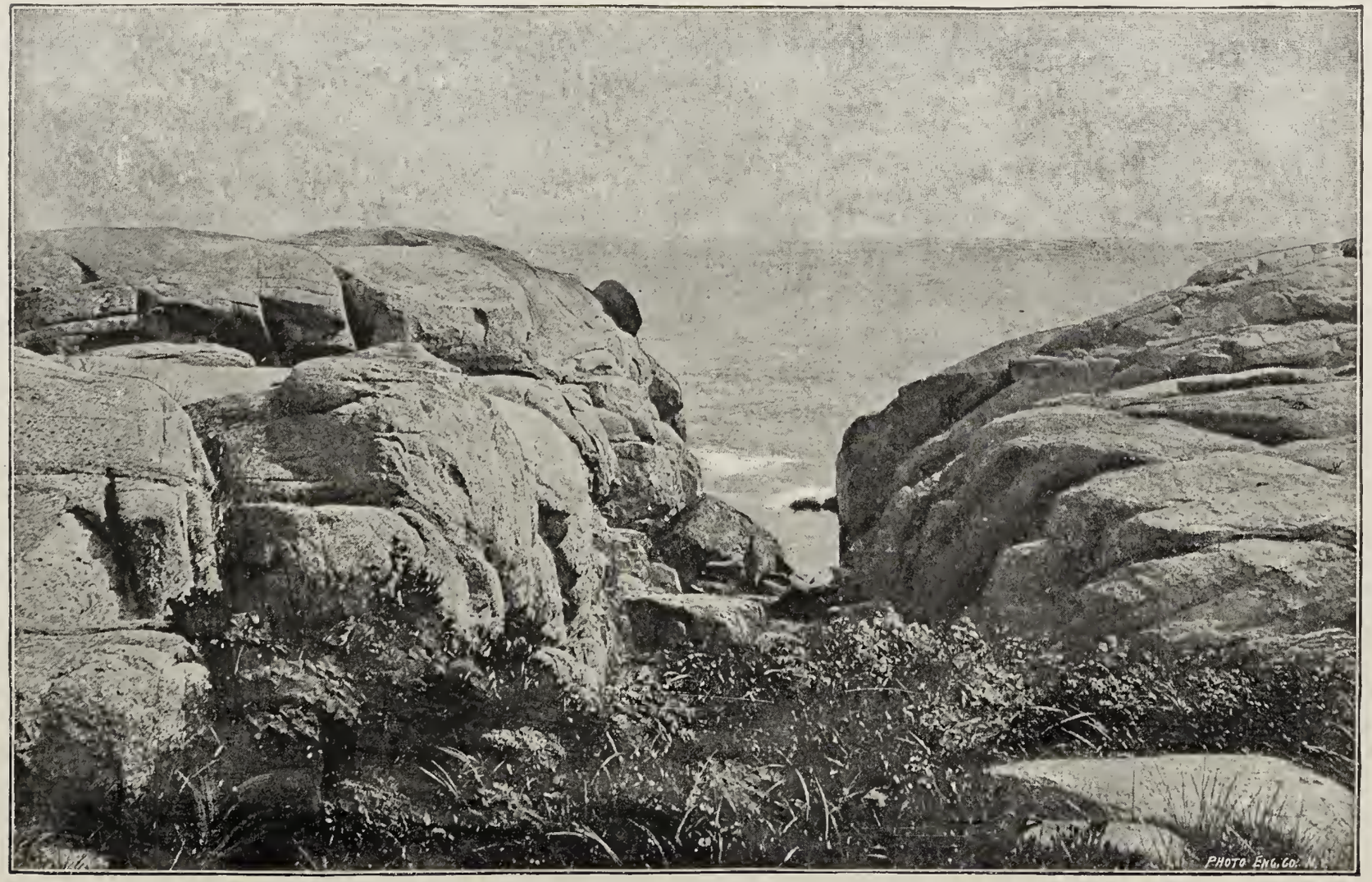
Through these granitic bed rocks, which compose about nine-tenths

of the foundations of the district, extend very numerous dikes. As will be seen on the map, considerable portions of the shore line are so far penetrated by these intrusions that more than one-tenth of the surface is occupied by them. Unfortunately for the completion of the observations, the internal area of Cape Ann as well as of the neighboring mainland is pretty deeply and evenly covered by glacial drift, more than three-fourths of those areas being hidden from view. All the evidence, however, goes to show that the proportion of dike stones to the common granites is quite as extensive in the interior and drift-covered areas as it is along the extended shore line.

On top of the bed rocks we have, as before remarked, an extended sheet of drift deposits distributed with greater uniformity than along any other portion of our shore known to me. As will be seen hereafter when we come to set forth the results of special study on this drift deposit, it consists mainly of frontal moraine or material which has been shoved forward at the front of the ice sheet.

In none of its geological features, neither in its bed rocks nor in the injected materials nor in the drift, does the region of Cape Ann have an individual character. The granitites which appear and which constitute the greater part of the region are essentially like those occurring all about the borders of Massachusetts Bay. With slight exceptions the dike stones are paralleled by others found in various parts of eastern Massachusetts. The morainal accumulations are but fragments of a large field in which these deposits occur. The peculiar advantage of this district, that which has led me to make it the subject of a memoir, is found in the fact that several geologic features exhibited there are better placed for inquiry than elsewhere. It will be evident from an inspection of the maps that the Cape Ann promontory is formed by the northeastern projection of a ridge of crystalline rocks, generally syenitic, extending from near Dedham, Mass., in a northeasterly direction, until cut off by the sea. To the northwest and to the southeast of this extended axis we have rocks of a less crystalline nature verging upward into distinctly sedimentary deposits. On the south side of Boston Bay, extending from Nantasket in a southwesterly direction, we have a similar axis; the two are obscurely united at their southwestern extremity in the highlands and peaks of the Blue Hills, which attain a considerable altitude.

The general structure of these ridges makes it clear that they are in their nature anticlines, and that the Blue Hills district is situated at the southeastern extremity of the trough which is inclosed between them, thus forming what we may term the node of the anticline. Between these two anticlines, within which lies Boston Bay, we have a much disturbed syncline, the only portion of which open to investigation lies in and about the city of Boston. The greater



ERODED DIKE CHASM NEAR WHALE COVE, 20 FEET ABOVE PRESENT SEA-LEVEL.

VIEW NEAR CAPE HEDGE, MASSACHUSETTS, SHOWING SCOURING ACTION OF SEA ON LITTLE-JOINTED ROCK OF VARYING HARDNESS.

portion of this syncline has been entirely cut away by erosive action, by the work of rivers, by the action of the sea, and in larger measure by the erosive power of glacial ice. So profound has been this erosion, that it has not only destroyed the greater part of the sedimentary deposits down to the water-level, but it has also removed a considerable portion of the plutonic rocks which were thrust up beneath the old anticlines, at the same time stripping off all the newer-bedded rocks which originally lay upon their surface.

It is also evident that profound faulting attended the formation of this syncline, accompanied by a considerable development of minor folds within the field occupied by the syncline itself. Through these faults extensive extrusions of igneous rock took place, in part in the form of dikes and in part in the form of more superficial flows, the remains of which are still found in a profoundly eroded condition in the porphyries and felsites of Lynn and in the similar rocks and accompanying ash-beds of Cohasset. From what is left of the old syncline we may fairly arrive at the conclusion that only the southeastern extremity of this trough has been preserved to the present day. By far the greater part of its area has been deeply eroded and is hidden beneath the surface of the sea, in part covered over by recent accumulations of sediment. We shall consider the history of this erosion when we come to treat of the recent abrasion which has taken place on the surface of Cape Ann.

GENERAL FORM OF CAPE ANN ANTICLINE.

Turning now to the general form of the Cape Ann anticline, as we shall hereafter term it, we find that it consists of a somewhat irregular ridge having an average width of about ten miles. On the north this ridge is bordered by lowland worn in the softer rocks which lie upon its north side, and occupied in the main by the drainage of the Charles, the Mystic, the Saugus, and the Ipswich Rivers. The delimitation of the ridge on the north is by no means distinct; it is, however, sufficiently clear to give a certain accent to it on that side. On the south side it is bordered by the waters of Boston Bay.

The surface of this anticline, though originally united, is now much divided by a number of tolerably deep valleys, some of which attain to the level of the sea. The southernmost of these, that of Charles River, attains very nearly to the sea level, the highest point of the ridge where it is crossed by the stream being not more than fifty feet above tide mark. The Mystic also forms a deep excavation through the anticline; the Saugus River, though its headwaters do not extend beyond the limits of the ridge, deeply divides it. From Manchester to Essex another depression appears in the axis which attains almost to the level of high tide, and the fiord which separates Cape Ann from the mainland extends, save for the postglacial dé-

bris which has accumulated in it, to a considerable depth below the water line. These several troughs owe their existence to pre-glacial streams and in larger share to the work of the ice during the last glacial periods. Besides these conspicuous meridional valleys we find many others having the same general trend and probably to be explained in the same manner, through the action of glacial ice operating on rocks which were mechanically weak.

Besides the above-mentioned valleys this region exhibits another series of depressions, less conspicuous because they are not to the same extent occupied by water, but on the whole equally noteworthy. These valleys extend in the direction of the anticline itself, having a general trend of about N. 10° to 20° E., S. 10° to 20° W. (See Pls. XXXVI, XXXVII.) Although tolerably evident in every part of this ridge, these valleys are most conspicuous in the region in and about Cape Ann. On this island they give more expression to the surface than any other elements of its topography. With the map of the island before him the reader will perceive that the Cape is in good part divided into two regions by the deep indentation of Gloucester harbor and a corresponding indent known as Sandy Bay. Between these two depressions, each of which has a length of several miles, the surface of the Cape is, save for the encumbering envelope of drift, much lower than along the other part of its area. If it were depressed fifty feet below its present level, although but a small part of its surface would be submerged, a nearly complete channel would be formed extending from Rockport to Gloucester, and Eastern Point would be cut off from the main island. Besides this most considerable northeast and southwest valley, there are several others approximately parallel to it on different parts of the island and on the neighboring mainland. One of these extends from the indentation just west of Halibut Point, known as Folly Cove, for a distance of more than two miles into the body of the island. It is possibly protracted across the intervening space to Squam River near Riverdale, though in its central portions it is almost completely effaced by the thick deposits of morainal matter.

The last-named group of valleys has an origin which is not as simple as those which extend in a northwest and southeast direction. In part they are due to glacial erosion on portions of the strata which are mechanically weak. As will be seen by the map, certain belts of dikes containing the most numerous and characteristic of these intrusions have the same course as these valleys. It is likely that the resistance of the rocks to glacial erosion was considerably diminished along the lines which they occupy, and that in part the development of valleys is due to this cause; in part also they may be attributed to a totally different origin. The direction of the morainal fronts corresponds approximately to that of these valleys. The morainal matter is arranged in successive ridges roughly par-

VIEW NEAR CAPE HEDGE, SHOWING SCOURING ACTION OF SEA ON LITTLE-JOINTED ROCK OF UNIFORM HARDNESS.

VALLEY BETWEEN BRIAR NECK AND MAIN-LAND, LOOKING NORTHEAST—THATCHER'S ISLAND LIGHT-HOUSES IN DISTANCE—SHOWING ONE OF THE NORTHEAST AND SOUTHWEST VALLEYS OF CAPE ANN.

allel, the intervening valleys having often the same general character as the troughs produced by the erosion of the bed rock.

Besides the northwest and southeast valleys which are evident in the topography of the country, it is clear that there is at least one other beneath the level of the sea lying in the space between the Salvages and the eastern shore of Cape Ann. Yet another more obscurely indicated lies between Straitsmouth Island and Gap Head, being continued southwardly between Thatcher's Island and Milk Island. Judging from the soundings, it appears likely that there are other north and south troughs partially effaced by sediments on the sea floor farther out from the shore. One such appears about three miles east of Straitsmouth Island and yet others farther out to sea. The insufficiency of the soundings, which, though numerous enough to serve the needs of the navigator, do not meet those of the geologist, makes it impossible to determine with accuracy the form of these interesting troughs.

The soundings also indicate, though obscurely, the extension of the Cape Ann ridge for ten miles or more eastward of its present limit. The ridge which appears to represent the submarine continuation of the Cape is much lower and more rounded than the portion of the anticline which lies above the water level, but the distance between the soundings is so great that a basis for precise conclusions can not be secured.

The height of the anticlinal ridge which includes the district of Cape Ann is remarkably uniform. The most elevated part of it does not lie within the field we are considering, but is found at Bear Hill, in the township of Stoneham, where it is about four hundred feet above the level of the sea. Within the limits of Cape Ann the highest point is about two hundred feet above the sea level. The depths of fiord-like indentations which extend in a northwest and southeast direction is not accurately determined, but probably at no point does it exceed one hundred feet below the ocean level. At first I was disposed to consider this uniformity in height as due to the likeness of glacial action on different parts of the surface. Further inquiry has convinced me that it is to be explained by the operation of the sea in the former geologic periods, when it was at a somewhat higher level than at present. All along our coast we have more or less clear indications of a great planing agent, which has cut off the summits of the mountains back a distance of scores of miles from the present shore line, reducing the surface to something like a general level, leaving a few isolated peaks here and there upon the bench. The level of this bench varies on different parts of the shore. In Massachusetts it ranges from the present level up to the height of about four hundred feet. In Virginia this marine bench is more distinct than in New England, for the reason that its aspect has been less affected by glacial action.

Owing to the action of the sea in former times at higher levels, the mountains of the coast belt, though having as much geological relief as those of the interior region, have been deprived of their topographic value and are planed down to the very roots.

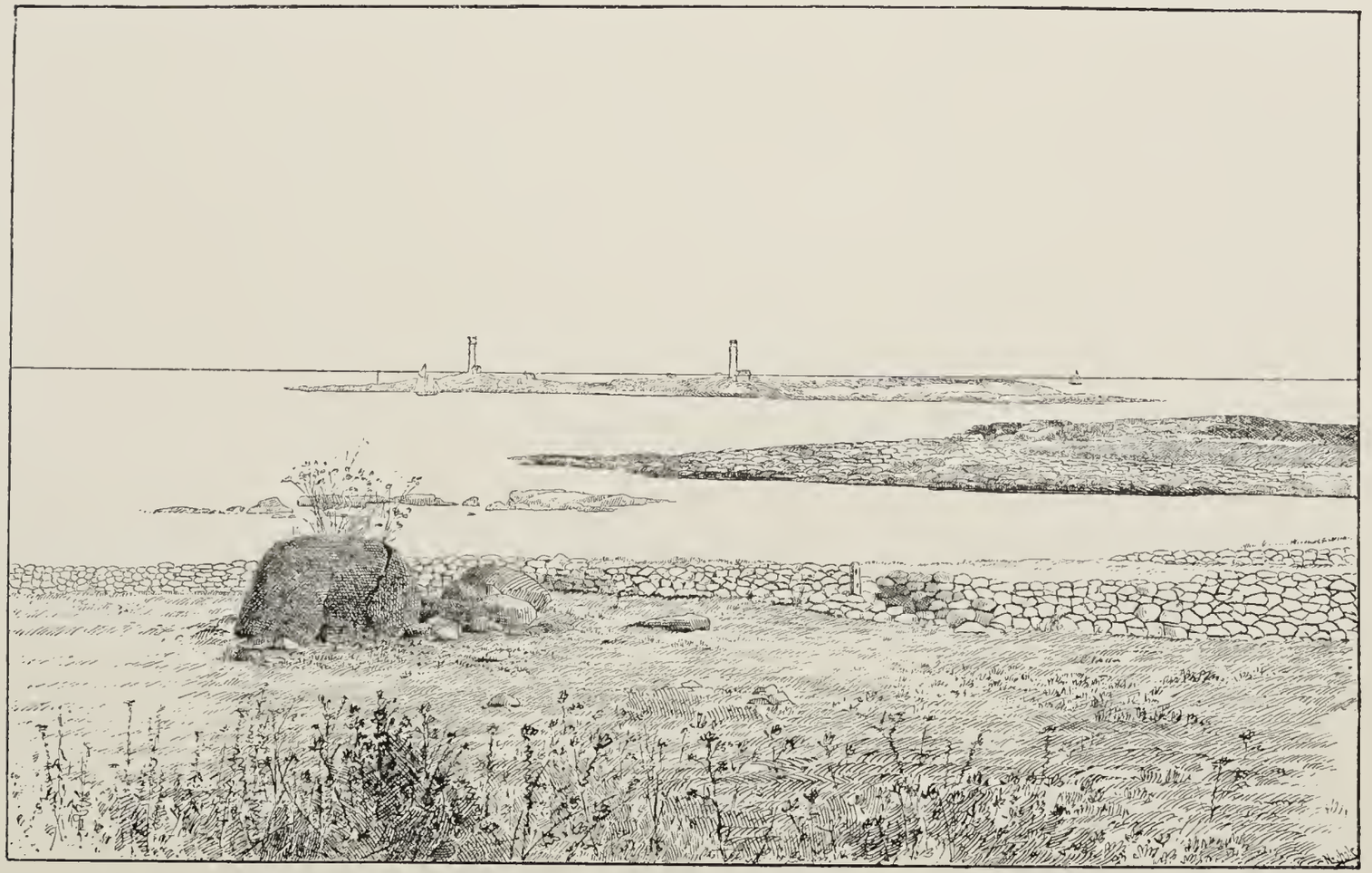
NATURE AND DISTRIBUTION OF DRIFT DEPOSITS.

The drift deposits of this region, though in general character much like those found in the neighboring districts, presents some interesting peculiarities. The whole of the central field of the island of Cape Ann and the neighboring portions of the mainland included in this report is covered with a coating of frontal moraine somewhat irregularly distributed but generally attaining a considerable depth. Here, as generally elsewhere, the accumulations consist of three elements: shoved material, or that which has been urged forward in the advance of the ice sheet as the soil is carried onward in front of a scraper. (See Plates XXXVIII, XXXIX, XL, XLI.) Around this shoved matter, or that which owed its transportation to the advancing ice front, we find accumulation of finer material arranged in the form of kames. (See Pl. XLII.) Yet farther from the former face of the ice lie sheets of sand arranged so as to afford a tolerably horizontal surface to which I have given the name of "frontal aprons." On top of the shoved moraine, and for some distance back of its line, we find deposits which have received the name of "ground moraine," composed of materials originally contained in the body of the ice which at the time of its melting dropped upon the surface.[1]

SHOVED MORAINES.

The frontal or shoved moraine material within the limits of the island of Cape Ann is remarkably thick, having on the average a depth exceeding fifty feet, and at some points possibly exceeding one hundred and fifty feet. (See Pl. XLIII.) It is arranged in the form of rudely parallel ridges, which extend from N. 25° to 40° E. and S. 25° to 40° W. These ridges are very broad and the valleys between them by no means distinct. In most cases they appear to be thickest on the summits of the low elevations of granitite, which are separated from each other by the valleys which we have already described. The surface of these morainal ridges is very irregular, being cast in the mammelate form so common in such accumulation. (See Pl. XLI.) The most remarkable feature observable in this morainal matter is the extreme abundance of large erratics which it contains. (See Figs. 44, 45.) These great bowlders are so abundant that over most of the surface occupied by the shoved moraine they make all tillage impossible. Indeed, on a large part of the area it is

[1]Geology of Martha's Vineyard, N. S. Shaler, Seventh Ann. Rept. U. S. Geol. Survey, 1886-'87, p. 314.



SHORE AT EMERSON'S POINT, WITH THATCHER'S ISLAND IN DISTANCE; LOOKING EAST.

SERPENT KAME DESCENDING NORTH SLOPE OF SOUTHERN FRONTAL MORAINE NEAR ROCKPORT; LOOKING SOUTH.

difficult to find a place to set the foot between the closely packed erratics. In the most of the morainal matter the proportion of bowlders exceeding one foot in diameter amounts to not less than one-half the total mass. At certain points the percentage of the large erratics is so increased that there is no fine material to fill their interspaces; the result is that the heap remains open, presenting cavities which extend in many cases to the depth of twenty feet or more below the surface, the whole mass appearing in the landscape like the ruins of Cyclopean masonry. (See Pl. XXXIX.)

Wherever the seeds of trees could have found soil enough to afford them root vegetable waste has filled the hollows between the stones and masked the position of many parts of this open-textured moraine. Nevertheless a considerable part of the accumulation, which I have estimated amount to one-fiftieth of the whole, remains completely without vegetable coating except for the lichens which have found place upon the erratics.

FORM OF DRIFT DEPOSITS.

Returning to our consideration of the general form exhibited by these deposits, we note that the southern part of each division of the shoved moraine appears to be steeper and more stony than the northern part. (See Pls. XL, XLI.) This is probably due to the overriding of the moraine in the frequent slight advances of the glacier, and in part to the washing of the sediments from the ice front upon the slope of the moraine as it was abandoned in the process of glacial retreat.

On the northern exposed face of the moraine, the boundary between that accumulation and the surface of the bed rocks is tolerably sharp. The partition between the two areas is generally indicated by a depression, in which lies a series of swamps. This depression is on an average ten to twenty feet in depth and has a width of several hundred feet. North of this trough there are occasional patches of what appears to be shoved moraine material; but the greater portion of the incomplete sheet of detritus apparently has the nature of ground moraine or that which was formed when the melting ice dropped its débris on the surface. At no point have I observed this accumulation having a thickness of more than five or ten feet, and the materials generally occupy less than half of the bed-rock surface.

Although the shoved moraine occupies about three-fourths of the area of the island of Cape Ann, the district contains representatives of the other structures which were formed on the front of the ice. The kame deposits are rare; they are mainly found either upon the southern portion of the island of Cape Ann and the neighboring mainland or on a narrow strip along the northern coast. The origin of these kame deposits can readily be explained, provided we accept

the hypothesis concerning their origin which I have elsewhere presented.[1] This hypothesis is, in brief, as follows: From beneath the ice mass there came forth many streams of flowing water, bearing with them great quantities of detrital matter. At the time when these streams flowed the base of the ice was considerably beneath the present level of the sea. On the floor of that sea, immediately in front of the glacier, the whirling currents, originated in the ocean waters by the swift-flowing glacial streams, formed the peculiarly distributed mounds and valleys of stratified débris which we note as kames. These subglacial streams were rare on the part of Cape Ann which is now above the ocean level, for the reason that they were drawn away into the deep valleys which lie east and west of its elevated mass. We know by the facts exhibited elsewhere that subglacial streams, though occasionally appearing along all parts of the ice front, are most likely to find their channels in the depressions of the surface which lie beneath that front. Thus the kame deposits were probably accumulated on territory which now lies beneath the surface of the sea.

In front of the kames normally comes the moranial apron which is so well developed in southern New England. This apron is scantily exhibited for the same reason that led to the paucity of the kame deposits. The materials which compose it were borne to their position by the waters from beneath the ice, and therefore where the kames are poor the apron will be imperfect.

Traces of this frontal apron exist along the southern shore of Cape Ann, especially near Gloucester and in the part of the island which lies east of that town. The traces are so imperfect that they would escape the attention of the geologist who encountered such structures for the first time in this field. The topography of the sea bottom south and east of Cape Ann indicates a general slope reaching outward for some distance from the shore. I have no doubt that the frontal apron determines the uniformity of this slope, as it manifestly does that of the sea bottom south of Nantucket and Martha's Vineyard, where a wonderfully developed frontal apron may be seen to pass below the plane of the sea.

As before remarked, the north shore of the island exhibits some deposits of kame materials and perhaps some faint indications of frontal moraine. It is probable that these structures represent the work of the ice when in its northward retreat it paused for a moment on the portion of the surface which lies below the level of the sea beyond the shores of Cape Ann and there constructed a frontal moraine with its corresponding kame and apron deposits.

As a whole the kame deposits of Cape Ann form an imperfect fringe, extending from Andrews Point westward as far as Annis-

[1] Geology of Martha's Vineyard, Seventh Ann. Rep. U. S. Geol. Survey.

CREST OF NORTHERN FRONTAL MORAINE, LOOKING NORTHWEST; DOGTOWN COMMONS.

VIEW IN THE ROCKY MORAINE ON THE TOP OF GREAT HILL NEAR ROCKPORT MASSACHUSETTS ON WEST SIDE OF GLOUCESTER AND ROCKPORT TURNPIKE; LOOKING WEST.

quam up to the part of the island which lies next to that inlet and thence to Eastern Point. Faint traces of such accumulations lie on Eastern Point and back of Long Beach. Deposits of this nature are, however, distinctly more abundant on the western versant of the island than on the eastern.

Generally the stratified elements of glacial accmulations do not rise more than sixty feet above the sea level. They are hardly traceable in any continuity above the level of 40 feet; but at a few points they extend in an obscure form nearly to the summit of the great moraines. On Dogtown Commons several of these areas of kame deposits were during the period in which this district was inhabited brought into the state of tilled fields, and now appear as samll pasture lands destitute of bowlders. In part this destitution is due to the fact that the occasional bowlders obstructing the plow were removed. These high-lying benches of stratified drift material probably indicate points where small subglacial streams emerged during the process of the retreat of the ice, bringing forth a quantity of detrital matter and depositing it upon the surface of the shoved moraine at a time when the mass lay below the level of the sea. (See Pl. XLV.)

SERPENT KAMES.

Usually included among kames are those peculiar forms of the drift deposits often known in New England as Indian ridges, and to which I have provisionally given the name of "serpent kames," for the reason that they are usually serpentiform in their general shape, singularly recalling the artificial snake mounds of the West. Like the kames, they are composed of more or less stratified materials, and in certain cases they appear in positions which clearly indicate that in some way they are related in origin to the ordinary kettle kames.[1]

There is but one distinct serpent kame known to me in the field that we are considering. It lies on the eastern portion of the island of Cape Ann, near Rockport, on either side of the valley traversed by the railway and about twelve hundred feet southwest of the terminus of that road. Its position is shown on the map. (See Plates XXXVII, XXXVIII).

In many respects this serpent kame is the most interesting in this country. Its total length is not far from one thousand feet, but a portion of it lies on either side of the steep valley where it is found. The general position of the mass is indicated in the accompanying plate.

[1] It is likely that the Scandinavian "escar" is akin to our serpent kames, but as some deposits which have received that name are probably in their nature drumlins, that is to say, masses of till which have been shaped beneath the ice by the process of its movement, it seems to me best for the present at least to abandon the use of that term.

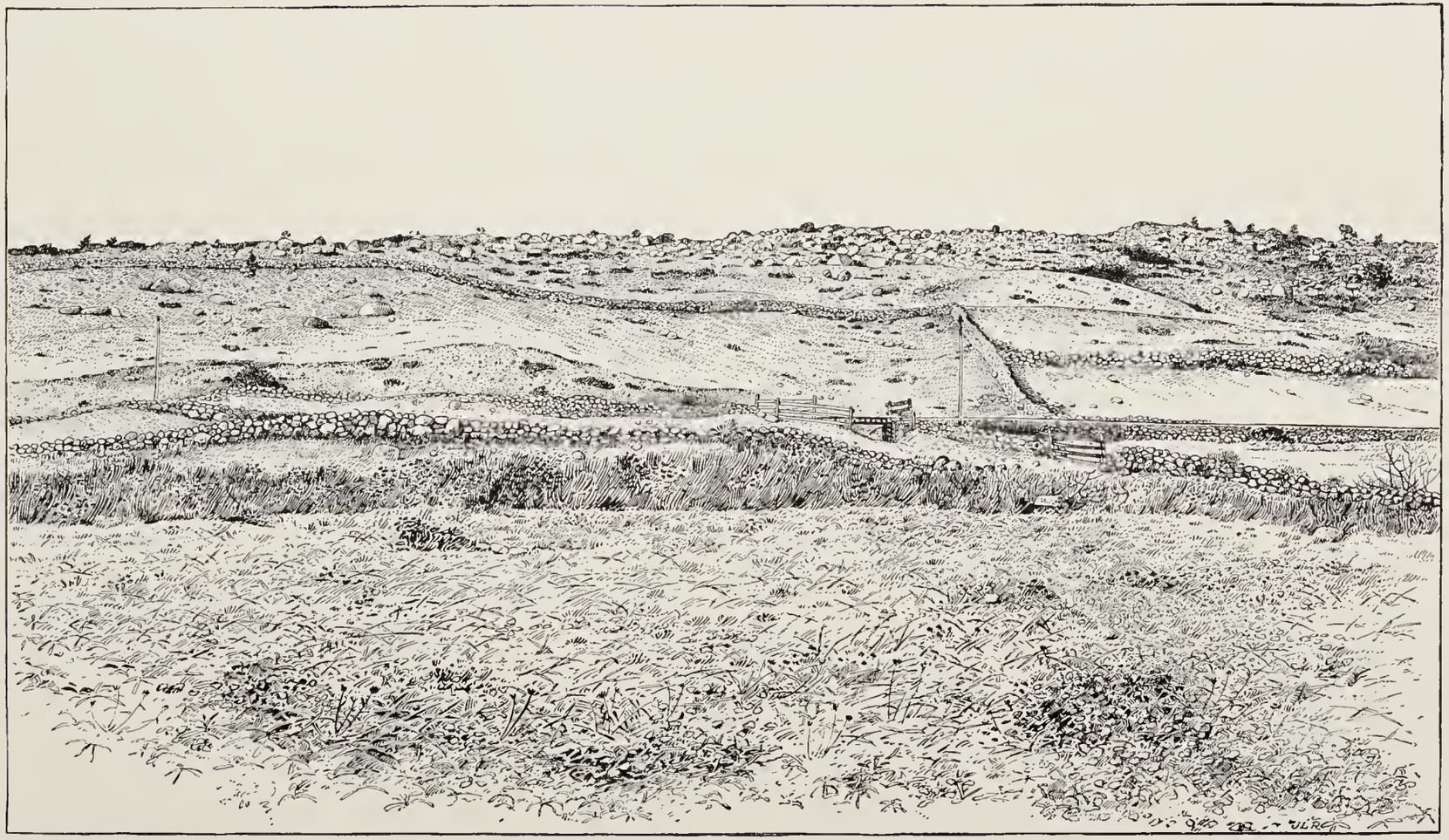
The central portion of the deposit has been in part cut away by the action of the small stream which traverses the valley; in part it probably owes its destruction to the former action of the sea at this level. This is the more likely from the fact that distinct though weakly developed terraces occupy a portion of the valley at a height where the serpent kame is destroyed.

I am disposed to hold, with other glacialists who have considered this problem, that the serpent kames have been formed in the following manner: The outflowing glacial stream excavated channels within the ice which they kept free as long as the currents were strong enough to scour their channels. In the closing stages of the ice sheet, while the front was no longer advancing or perhaps inclined to retreat, these arches were filled in by material borne by the diminished currents. This moraine gives us a better view of the condition of these channels than we obtain elsewhere. We perceive that they are closely molded to the surface, and also that they could be imposed upon considerable thickness of ordinary morainal drift.

DRUMLINS.

Besides the ordinary frontal deposits above noted, we have in this district a solitary representative of another class of glacial deposits, viz, that of drumlins. This single drumlin lies near Rockport and is known as Pigeon Hill. (See Pl. XLVI.) It is a remarkably good example of its class, and appears in very striking contrast to the surrounding topography. Rising to the height of about two hundred feet above the level of the sea, it has a very symmetrical lenticular form, departing from that outline only on its southern side, where there is a peculiar benching. Unlike the shoved frontal moraine, which lies about it, this ridge is composed, as is usual, entirely of these structures of very compact till in which the proportion of clay is large and the mass extremely compact. Its surface was originally covered by the coating of ordinary ground moraine, containing many bowlders, which have been removed in order to fit it for tillage.

The origin of these peculiar masses of compact till occurring in the form of drumlins is still a matter of debate among geologists. I venture to suggest the hypothesis that they are to be accounted for in the following manner: During the first stage of the Glacial Period the ice sheet had a very much greater extension than during the second portion of the Glacial Period. When at the close of the first stage the ice retreated, it left upon the surface irregular but in places extremely thick deposits of till. During the interval between the first and second stages of the period the southern part of New England remained for a long time free from ice. During this time the till deposit left upon the surface was much eroded, perhaps by the action of the sea, in part doubtless by river action. When the second advance of the ice came to repossess the



SERPENT KAME DESCENDING SOUTH SLOPE OF NORTHERN MORAINE NEAR ROCKPORT; LOOKING NORTH.

ELEVATED KAME PLAIN IN MIDST OF FRONTAL MORAINE, DOGTOWN COMMONS ONE MILE NORTH OF GLOUCESTER; LOOKING SOUTH.

surface, it wore away a large part of the till formed during the first period, leaving the remains of it carved in the characteristic form of our drumlins. It is obvious that these drumlins or lenticular hills have, as the latter name indicates, precisely the form which is given by the action of the ice to any resisting materials of uniform hardness over which it moves. Thus in the Adirondacks, and elsewhere where rocks of uniform hardness exist over considerable fields, we find that glacial action shapes their forms so that at a little distance they are readily mistaken for drumlins.

If this view be correct, Pigeon Hill is a solitary remnant of the original till of the first stage of the Glacial Period, the remainder of that deposit having been worn away by the later action of the ice or entirely covered beneath the thick deposits of shoved moraine.

The outline of the shoved and ground moraine in other parts of the island leads me to suspect that there are several other remnants of this ancient till so far buried beneath the subsequent deposits that their existence can only be conjectured.

A little observation will show the student that nearly the whole of the true frontal moraines in this district have a somewhat drumloid aspect. Each of the moraines is composed of closely crowded hills, the bases of which are conjoined. Looking at these elevations from the east and west, we perceive that they have the general shape of lenticular hills; the curves are not as finished as those of Pigeon Hill or other normal deposits of this nature, but they are of the same general form. In many cases if the encumbering masses of great bowlders were removed the likeness to drumlins would be even clearer than it is at present.

The rounded aspect of these projections of the central moraine is probably to be explained in essentially the same way as that by which we have endeavored to account for the drumlin proper. As is well-known, the front of the glacier is always instable in its position, and a peculiar measure of instability appears to characterize this marginal part of the glaciers belonging to the continental type. We may therefore assume that the cliff-like front of the ice again and again advanced and receded in its position, and at each forward movement there must have been a certain erosion of the deposits which were accumulated during the preceding advances. Although this feature is not very recognizable in the case of this moraine, it is remarkably evident in the Martha's Vineyard moraine, where the overlying of the drift deposits in successive advances is extremely conspicuous.[1]

[1] Geology of Martha's Vineyard, Seventh Ann. Rept. U. S. Geol. Survey.

COMPOSITION AND NATURE OF GLACIAL MATERIALS.

The composition and nature of the materials in the glacial deposits next deserve our attention. Turning first to the shoved moraine, we notice in the first place that the clay element so common in most glacial deposits exists in very small proportion in these accumulations. The whole of the mass has the washed appearance which indicates the extensive action of water at the time of its deposition, an action which has resulted in removing not only the clay proper, but also a very large part of the fine sand. Whatever be the nature of the rocks on which a glacial sheet operates a very large portion of the detrital matter is reduced to the fineness of clay and sand. Observing the eroded surfaces in this vicinity, we find that not less than three-fourths of the material removed from them has come from the scratches and the polishing which the ice applied to the surface, and not more than one-tenth from the plucking out of large bowlders such as now compose at least half of the shoved moraine on this island and the neighboring parts of the mainland. This forces us to the conclusion that the shoved moraine does not include all of the material taken from the rocks over which the ice moved, but only the coarser parts of that matter, the finer having been carried on to more distant points.

In this field as elsewhere we note that the material contained in the shoved moraine has a more uniform character than that which is found in the two classes of kame deposits and in the frontal aprons. Thus the shoved matter of the great moraines consists, so far as my observation goes, entirely of granitic matter and the fragments of dike stones derived from the intersecting volcanic rocks, while in the materials which are found in the kames we note a very considerable proportion of slaty material as well as of crystalline rocks which are not found on the island of Cape Ann or in the immediately adjacent mainland. In the serpent kames the amount of this waste from sedimentary deposits exceeds five per cent.

The explanation of this peculiarity appears to be as follows: The subglacial streams transported the débris rapidly and under circumstances which exempted it from the grinding action of the ice. These conditions of movement enabled the débris to journey for considerable distances without being ground into the state of powder. On the other hand, the shoved moraine, representing material subjected to powerful attrition, has journeyed for a much less distance, and so these streams have brought to this ground a portion of the detritus worn from the sedimentary deposits which occupy the syncline lying to the northwest of the anticlinal axis which constitutes Cape Ann.

In both the shoved moraine and the kame deposits we find by far the greater part of the material to consist of débris essentially like

SECTION OF FRONTAL MORAINE ON SIDE OF WARNER STREET, GLOUCESTER, MASSACHUSETTS.

SECTION OF FRONTAL MORAINE AT ROCKPORT, SHOWING RELATION TO BED ROCKS.

that exhibited on the surface of Cape Ann. This leads me to the conclusion that crystalline rocks of this axis extend for some miles north of the present shore ; a view which is borne out by the character of the rocks exposed in the townships of Essex and also in the southern portion of Ipswich. Both in the kame and in the shoved deposits of this morainal field we observe occasional fragments of gneissic rocks. This waste indicates the existence of a belt of gneiss overlying the injected granites in the country to the north of this district.

Fig. 42. Perched acuminate bowlder on roadside near Rockport Granite Company's quarry.

The bowlders contained in the shoved moraine usually have a very angular aspect. (See Pls. XLVII, XLVIII, and Fig. 43.) Indeed, no morainal matter of this nature known to me in New England, except at certain points in Maine, exhibits the angularity which we find characteristic of the bowlders in this field. They are also noticeable on account of their large average size. As will be seen from the list of the twenty largest bowlders which have been observed, none of them attain dimensions at all comparable to the greater erratics in other districts. Yet, as will be seen from the figures which give the general aspect of the stonier portions of this moraine, the number of the fragments exceeding a hundred cubic feet in volume is very large. We can frequently find on the surface of a single acre as

many as fifty whose average dimensions exceed one hundred cubic feet of mass.

Twenty largest bowlders.

Feet.			Feet.			Feet.			Feet.		
12 by	16 by	6	15 by	14 by	13	17 by	15 by	10	16 by	14 by	14
15	10	9	15	15	18	16	18	11	15	18	12
30	25	18	18	12	11	15	12	9	13	12	10
20	15	14	8	9	6	21	15	13	20	11	13
15	15	12	20	9	11	12	18	14	14	9	16

In the kame deposits we find here as elsewhere that true bowlders are very rare. Those less than a foot in diameter, which have been called by Chamberlain "bowlderets," are not uncommon, though at no point really plentiful. By far the greater portion of the kame material consists of sand, gravel, and pebbles of a rounded form.

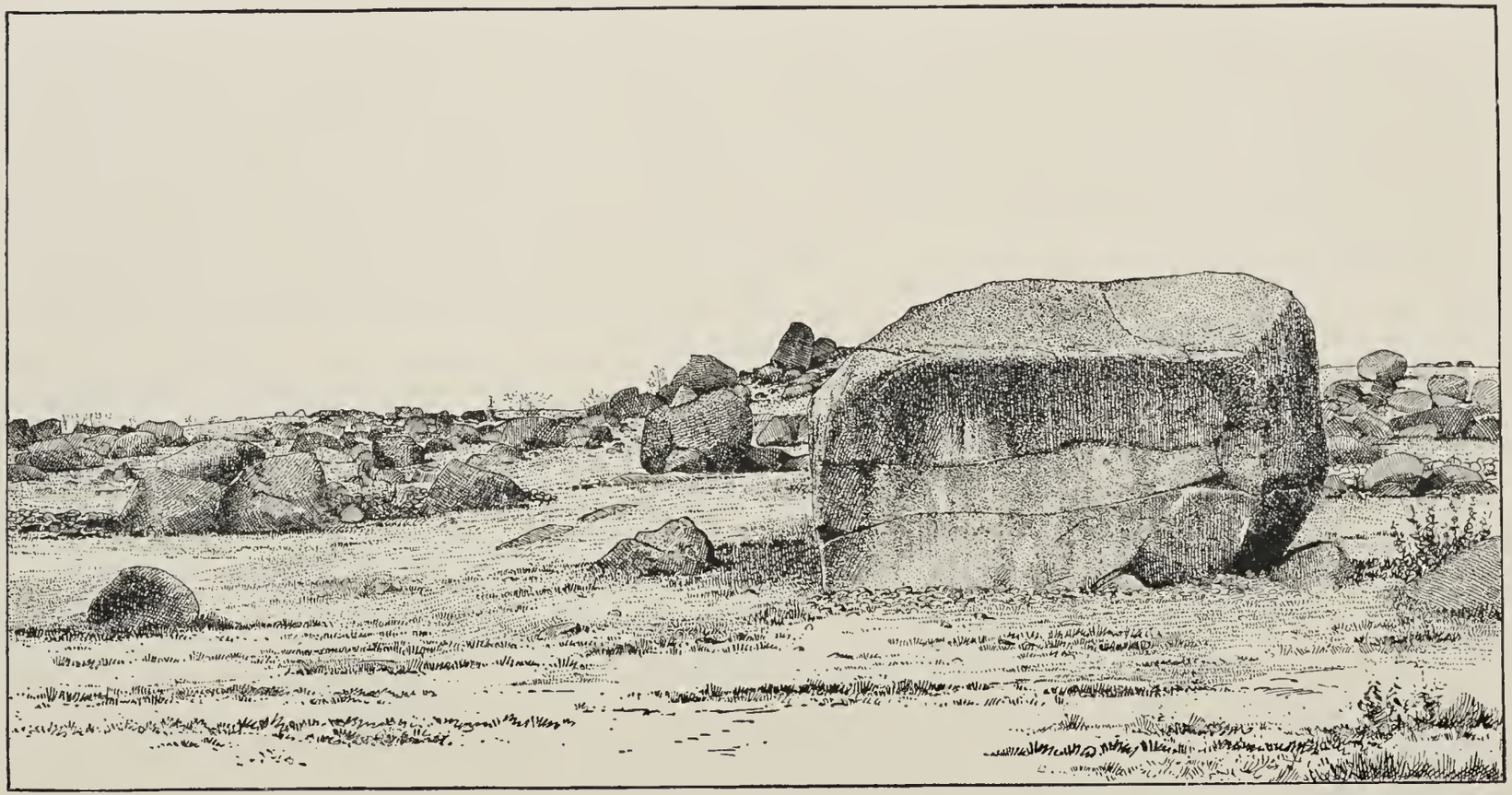
Although the kame deposits are almost entirely limited to the lowlands, we find on the hills of shoved moraine not only the single specimen of serpent kame before noted, but also several small patches of a kame nature, none exceeding three or four acres in extent, and always more or less commingled with ordinary erratics. It is evident that these kame gravels have been imposed upon the surface of the shoved moraine in the form of an overlying sheet.

DECAY OF BOWLDERS.

The extent to which decay has attacked the materials of these morainal accumulations is exceedingly diverse, and affords an interesting subject for inquiry. Within the mass of the kames or shoved moraine the measure of decay is very small. Only a small part of the material exhibits any indication of disintegration. On the surface of the deposits, however, we find extensive marks of corrosion. This process of decay is indicated in two ways:

In the first place, the superficial bowlders are frequently riven by cracks, which follow the natural joint planes of the rock. These crevices are usually opened by the mechanical action of the frost, though they exhibit a certain amount of decay along the lines of fracture. Perhaps one-fifth of the bowlders are broken up in this manner, thus having the surfaces exposed to corrosion very much extended. The figures given herewith exhibit in a clear way the effect of this development of incipient fracture lines. The facts serve also to show us that at the time when these fragments were rent from their bedding places the joints, which have afterwards developed under the action of frost, were completely sealed, affording no lines of weakness or incipient fracture. (See Pl. XLIX.)

There is another and yet more interesting form of decay which is in its nature more truly corrosive. A walk over the surface of the shoved moraine shows us in particular parts of it, especially near its western extremity on the island of Cape Ann, frequent cases in



NORTHERN SLOPE OF PRINCIPAL NORTHERN FRONTAL MORAINE, WITH PART OF ELEVATED KAME PLAIN, DOGTOWN COMMONS; LOOKING SOUTH.

PIGEON HILL QUARRIES; DIKES CUTTING QUARRY ROCKS; PIGEON HILL DRUMLIM IN THE BACKGROUND.

which the bowlders have decayed to a greater or less degree. Sometimes—indeed commonly at the first stages of this corrosive action—the surface of the bowlder which is exposed to the weather remains in a tolerably solid form, while the internal part of the mass has so broken up that the crystals do not adhere to each other. On the under side of the bowlder, where it is partly supported by other erratics, we may note that it is falling into the state of crystalline gravel. Yet further processes of decay may reduce a great erratic to a mass of disintegrating crystals, containing perhaps a core of material, a small fragment of the original bowlder, all the rest having fallen into small bits. A still further stage in the decay may give us a low mound of detritus, over which the vegetation is gradually mantling. Finally, the place where a bowlder contained a mass of one or two hundred cubic feet may appear as a low grassed mound. On some selected areas in the portions of the field where this action is most evident we find that one-fifth or more of the erratics are in an advanced stage of decomposition.

The surface of the bowlder may remain in a measure intact while the interior is greatly decayed. In such cases we generally find that the surface, though retaining at times its original glaciated character, is much riven by crevices, which indicate a process of enlargement of the mass probably arising from kaolinization of the feldspar which it contains. It is readily observed in the field—indeed it is clear from an inspection of the views given in this report—that the bowlders are divided into two distinct groups, those which decay interstitially and those which remain intact. By far the greater part of the bowlders though—even those of very large size, which have never been protected by any kind of soil coating—remain at the depth of six inches below the surface essentially unchanged by the action of the atmosphere. Often they still retain a surface which has probably been little changed since it was impressed by the glacier. Certainly on the average of bowlders more than six feet in diameter the loss in depth of material has not exceeded two inches, and the mass of the bowlder remains as sound as if it were in the original bedding. In several cases, one of which is shown in the figure (see Pl. XLVIII), we observe that a portion of the bowlder has gone to complete decay, while another part remains essentially unaffected by the corrosive forces. We also note the fact that there is no complete gradation between the bowlders which are perfectly protected and those which are greatly decayed. These facts make it clear that the decay is due to some local peculiarity which is found in certain portions of these granites. At first I was disposed to attribute this peculiarity to the chemical constitution of the mass, but close inspection of the material leads me to the conviction that this is not the true explanation of the phenomenon. It is more likely to be explained by the presence or absence of the peculiar close-set joints, which, as we shall note in

our study of the structure of the granitites, varies remarkably in different portions of this field. These crevices admit the entrance of water into the mass. The action of frost then produces the same effect upon the mass as it does upon rocks which are penetrated by a slaty cleavage; expanding in the crevices, they are forced somewhat apart, and the way for the penetrating waters made yet more open. (See Pl. L and Fig. 44.)

FIG. 43. Bowlder disrupted by action of frost and the roots of trees, midway between Gloucester and Rockport, west side of road.

AMOUNT OF EROSION DURING THE GLACIAL PERIOD.

The general configuration of the promontory of Cape Ann makes it probable that very extensive erosion has taken place in the mass in relatively modern times. It should be noted in the first place from the map, the accompanying sections, and the general description which we have given of this anticline, that it owes its relative relief to the erosion of the synclinal deposits which lie northeast and southwest of the ridge itself. An inspection of the general geology of this district shows us that the synclines which are found in it are generally deeply eroded. That in which lies Boston Bay is so deeply carved as to form a considerable indentation of the shore. A similiar erosion has taken place in the syncline which lies north of Cape Ann ridge, but owing to the fact that the basin is very extensively occupied by drift accumulations, it does not appear as a considerable bay. Yet if this drift material were removed the sea would penetrate as far up the valley of the Merrimac as Lowell,

VIEW NEAR STONE BRIDGE ON THE LINE OF THE EASTERN RAILROAD, ONE-FOURTH OF A MILE NORTHEAST OF GLOUCESTER STATION, SHOWING SOUTHERN MARGIN OF MORAINAL RIDGE.

PERCHED BOWLDER, 13 BY 8 BY 5 FEET, ON SIDE OF ROAD TO COFFIN'S BEACH; GRANITITE BOWLDER ON BED ROCK.

and would occupy a large portion of the field lying to the south of the Merrimac River. The bay would probably be larger than that of Boston, and its surface would, if the drift were thus stripped, be interrupted by only a few rocky islands.

The contour of the surface of Cape Ann, so far as we may judge of it in the present condition of embarrassment from the drift covering, appears to indicate the development in the preglacial period of an extensive system of mountain valleys such as normally form the headwaters of considerable streams. These valleys have been in certain cases deepened and in others been partly destroyed by the action of glacial erosion. Although I am disposed to account for these depressions on the supposition that they have been in a good degree the result of glacial wear, I am inclined to think that this wear served merely to deepen and in part to change the outlines of the original depressions worn by their water.

The general aspect of this topography leads to the conclusion that it could not have originated with the surface of the country at its present elevation above the sea. It appears necessary to suppose that the base level of the erosion was considerably higher at the time when these valleys were developed than it is at the present day. Not only on Cape Ann, but along the whole of this anticline, we find the lower portion of these valleys passing directly below the level of the sea, the submerged portions having been filled in mainly by stratified deposits formed since the close of the glacial period.

The fluviatile origin of these valleys of the Cape Ann anticline is distinctly proved by the fact that they widen and deepen in the natural direction of the drainage. If they were due altogether to glacial action they would not have this form. Still further, the hypothesis that they were produced by the action of free water is confirmed by the fact that in many cases they cut across deposits of diverse hardness in the manner so commonly shown in the action of streams, but unknown in that of glaciers, except where they are confined by the boundaries of pre-existing valleys formed by free water.

GLACIAL SCRATCHES.

The character of the rocks on Cape Ann, as well as the extensive covering of glacial waste, makes it difficult to ascertain the movements of the ice during the last Glacial Period. Such scratches as have been observed are marked on the accompanying map. They indicate that in general the course of the ice movement was from the northwest or between that point and north. Here, as elsewhere on the coast, the detail topography of the bed rocks evidently affects the glacial movement, so that without a larger number of observations than it has been possible to make in this field we can not determine the general direction of the flow with much accuracy. Some years ago I made observations upon the series of scratches at a locality

between Pigeon Cove and Folly Cove, which locality has since been destroyed. Observations show two successive directions of glacial scratches, the one trending from northwest to southeast, the other passing from north to south. Of these the scratches extending from northwest to southeast appear to have been the last formed.

Such variations in the scratches I once deemed of importance as indicating alterations in the direction of the ice movement in the later glacial time. I have observed similar cases along the shore from Eastport to New York. I am now inclined to think that the facts are of small value, for the reason that they show only such temporary alteration in the run of the ice currents as might readily arise from the changes in the strains of a body of such a nature moving over a rough area. The surface of rock on Cape Ann exhibits little trace of the strong grooves which form such a prominent feature in many parts of the glaciated district of North America. The reason for this is tolerably obvious. The hornblenic granitites of this area are very hard; as a whole, much harder than the rocks lying to the northwest, which have afforded the erratics that have impinged upon Cape Ann. The result is that the cutting tool, being softer than the substance to which it was applied, has itself given way. The glacial erosion in this field has been effected rather by the plucking out of large fragments than by the removal of the bed rocks in the finely divided form produced by scratching and grooving.

CARRIAGE OF ERRATIC MATERIAL.

There is a common notion that the drift in New England has generally been conveyed for great distances. The evidence obtained on Cape Ann would of itself be sufficient to disprove this supposition. This evidence goes to show that the detritus in the frontal moraines and till deposits has generally been carried but a very short distance. The average transportation of these fragments probably does not exceed one or two miles. Of the many thousand bowlders which have been inspected probably not more than a dozen are from beyond the field of hornblendic granitite on the island of Cape Ann or the neighboring mainland within a distance of six miles of Annisquam Reach, the exceptional fragments, not amounting to more than a ten-thousandth part, consist of bowlders which were apparently riven from the schistose rocks lying on the north side of the Cape Ann anticline. Two fragments observed, which clearly belonged to the coarse granite, contained large crystals of mica, which is extensively developed in the region about Lowell and Chelmsford. These bits, neither of which exceeds a foot in diameter, may have been carried for a distance of thirty or forty miles.

On Cape Ann, as elsewhere in New England, the kame drift has evidently undergone a more extended transportation than that which belongs to the group of till in the frontal moraine. The kame

PART OF NORTHERN FRONTAL MORAINE, DOGTOWN COMMONS.

(The ungrassed mounds show heaps of crystalline sand left by the decay of bowlders.)

material contains a good deal of waste, perhaps as much as a third of its whole mass, that has evidently been derived from beyond the limits of Cape Ann. The assemblage of materials is substantially that which we find in the drift of the Merrimac Valley. I am inclined to think that a large part of this débris was brought by subglacial streams from that part of the mainland. The proportion of material in the kame gravels derived from distant sources appears to be greater in the case of the serpent kames than in the other deposits of stratified gravels.

POST-GLACIAL EROSION ON CAPE ANN.

ATMOSPHERIC EROSION.

The post-glacial erosion of this district may be divided into two classes—that which is due to the action of surface water, and that which has arisen from the work of the sea on the coast line, both at the present level and at times when the shore was higher.

Considering first the atmospheric erosion, we find that in the main it has been exceedingly small. The area of Cape Ann is not sufficiently great to bring about the accumulation of the fluviatile waters in large streams. The considerable thickness of the drift mass in the upper parts of the island causes the discharge of water to be very regular, and the great prevalence of large bowlders restricts the cutting action of the brooks. Owing to the fact that the bowldery drift contains but little clay, the water penetrates deeply into it and is there stored, to be emitted in a very gradual manner. The frontal apron of the moraine lies almost altogether below the surface of the sea. Therefore this region wants the element of a glacial topography which is most readily cut up by flowing water.

The existing streams on the island, all of them of small size, occupy almost altogether valleys that are in no wise due to their own action, but have been formed by the accidents which have determined the position of the glacial drift. They generally lie in the lines between the morainal ridges, or, where those ridges are wanting, in the channels in the bed rock, which were worn to their present shape if not altogether formed, by the action of the ice. At certain points on the surface of the moraine, particularly on the southern slope, though occasionally occurring also upon its northern versant, there are narrow V-shaped valleys, somewhat clogged with bowlders, which appear to indicate the former existence of streams which were much more powerful than those now operating on the surface. I am inclined to believe that these channels may be due to the fact that in the time immediately following the dispersion of the glacial sheet from this surface and its re-elevation the rain-fall was much more considerable than it is at present. It is, however, impossible to make certain that these channels were not formed by tongue-like protrusions of the ice, which scoured away the portions of the mo-

raine which they traversed. It is true we do not find the heaps of eroded material which in other places often mark the action of such protrusions of the ice, but it is likely that these heaps lie beneath the surface of the sea.

On small areas of the frontal apron and kame sands which remain visible on Cape Ann we find a few shallow runnels, which have doubtless originated from the scouring action of the waters which now flow through them. These channels are, however, so insignificant as to merit no particular description. The only noticeable feature concerning them is that they extend to the present shore, with an inclination which shows that they have been lowered below the sea level in comparatively modern times.

MARINE EROSION.

The erosive action of the sea presents us with much more important phenomena than that which is due to atmospheric causes. Leaving for the present the question of the action of the sea at former levels above its present height, I shall now consider the effect upon the coast line of this district of the waves and the other erosive agents derived from the ocean.

The whole of the shore line of Cape Ann and that of the larger part of the mainland included within this report, except where small parts have been filled in by drifting sand and pebbles, lies upon the hard crystalline rocks which entirely compose the basement deposits of this region. On these rocks the ocean has exercised its usual erosive influence, due to two diverse causes. In the first place, the assault is accomplished by the beating action of the waves operating upon the cliffs by means of the fragments of rock which the surges impel against the shore. The work of erosion has also been greatly aided, at least in recent time, by the action of ice, which forms abundantly along the whole of this coast line, and operates in a way to advance the disintegration of the hard rocks.

The diversity of the effect of the waves upon the shores is very great. The measure of this action is greatly influenced by the structure of the rocks as regards the joint planes or incipient rupture lines which they afford. Where the rock is abundantly rifted, frost, acting upon the water which has penetrated the crevices, as is well known, breaks up the continuity of the mass. Again, the action of the waves is diversified in its measure by the character of the slope with which the land meets the sea. Thus where, as at several points, the shore descends abruptly into deep water, the waves are not armed with detrital matter, which by being impelled against the cliffs, serves to cut away the rock. Such cliffs are usually unaffected by the blows of the waves, and remain essentially unchanged as regards the outlines given them by glacial erosion. Pls. XXXVII and LII show the action of the sea under these circumstances.

POST-GLACIAL TALUS OF GRANITE PORPHYRY AT WEST GLOUCESTER, LOOKING NORTHWEST, SHOWING RAPID DESTRUCTION OF ROCK BY FROST ACTION.

Where, however, the submarine foundations of the cliffs are in water not more than thirty feet deep, such bowldery matter as may lie at their base is within the grip of the waves and is used by them for the assault of the cliffs. At certain points, where there is a compact detrital talus sufficiently near the surface of the water to admit of effective wave action against the fragments which lie on it, the action of the sea is such as to sweep away from the base of the promontory all the masses which accumulate there, and so protect the cliff against the attrition of the waves. The erosive action of the sea is the most effective where, as on the shore just east of Salt Island, the joints of the rock are so disposed that the frost may rive out the fragments and put them in control of the waves. At such point the sea has generally formed a distinct bench in the manner shown in Pls. XXXII and LIII.

Considering the shore as a whole, not more than a tenth of its line exhibits marine benching of a distinct character. On by far the greater portion of the line the original glacial form remains, with the exception that here and there a small portion of the material has been scarfed away by the combined action of waves and ice. Pl. XXXII exhibits the usual manner in which the line of coast meets the sea.

At first I was disposed to believe that the exemption from erosion was due to the fact that the rocks next the shore had originally been protected by a thick coating of drift, upon which for a time the energy of the waves had been expended, but on closer inquiry I find that the morainal matter of the island, though very thick in the interior district, is very thin next the shore. In a word, this distribution indicates that no considerable mass of such material at any stage of the history of the region since the sea attained its present level lay along the coast line. I am therefore forced to the conclusion that the absence of the marine bench is due in part to the brevity of the time in which the sea has operated at its present level and in part to the fact that the attitude and condition of the coast rocks is such as to afford the coasts a large measure of protection against wave action.

Where the original slope of the rocks towards the sea was very gentle, the waves, in place of striking a violent blow against them, slip up over their surfaces, producing a mere swash in place of an effective stroke. In this case the erosion may take the shape of scouring, as is shown on Pls. XXXIV and XXXV. Even where the rocks descend towards the surge with a steep angle, their structure must be jointed in a manner favorable for the action of the ocean surges, and there must be a talus at the proper depth beneath the surface to favor the movement of the erratics when flung by the waves against the cliff. These several conditions do not exhaust the category of the circumstances which affect the erosion of the shore. Where the

rock is much penetrated by dikes, these dikes are almost invariably less resistent to erosion than the country rock which bounds them, so the result is that under the operation of erosive agents—frost and waves—they become chasms, which serve to weaken the coast wall even where it is not otherwise enfeebled, and so bring about an extensive erosion of the shore. Examples of such action are shown in Pls. XXXIV, LIII, LIV, LV, and LVI.

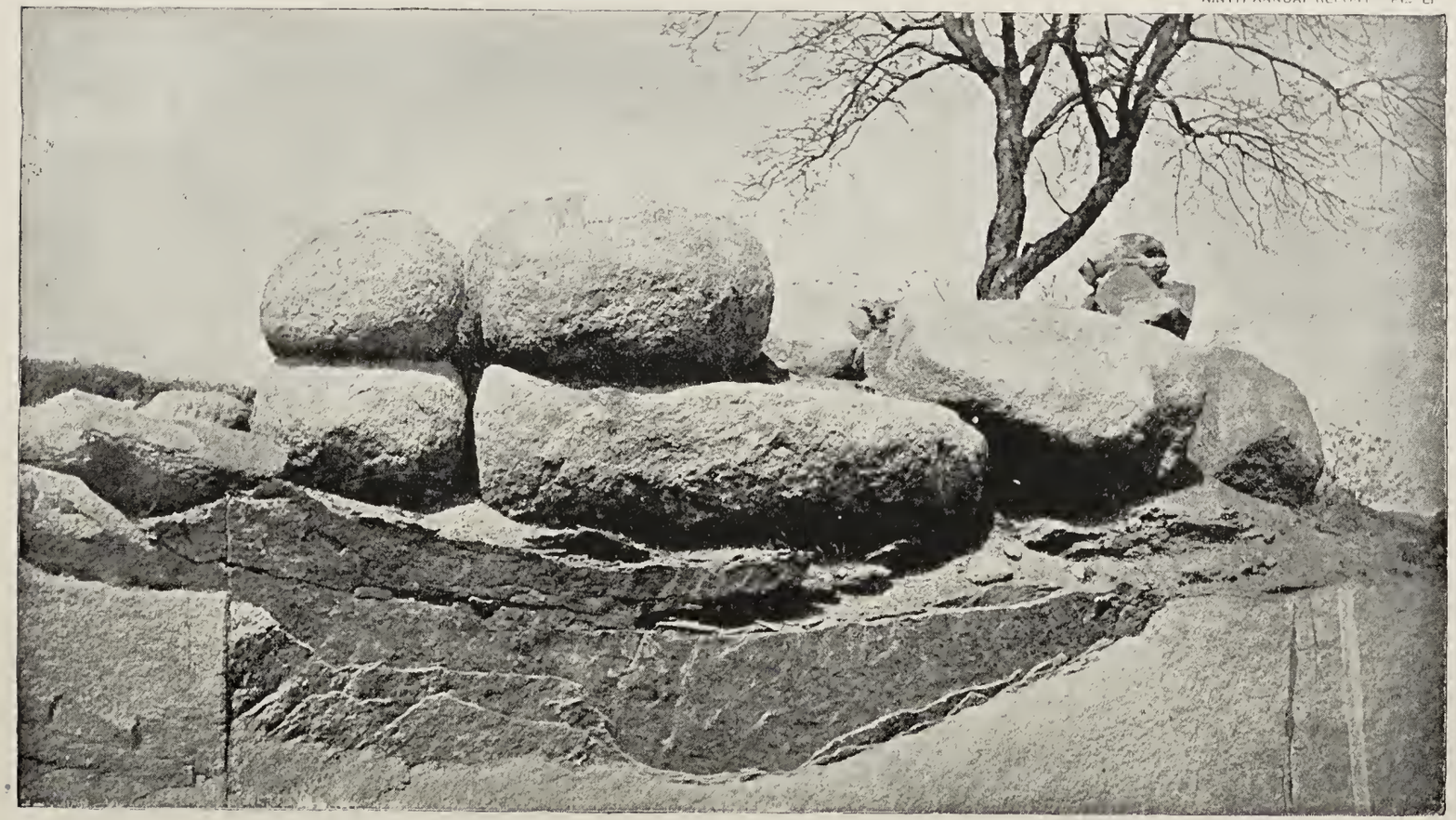
It is now necessary to consider not only the scarf which has been formed along the coast, but also the re-entrants or bays plentifully distributed along its line. Although not so diversified in outline as the neighboring coast of Maine, though formed of similar rocks, the Cape Ann coast presents us with numerous small fiord-like embayments. The reason for this difference is probably to be found in the fact that the strike of the obscurely separated granitic masses on the surface of Cape Ann is nearly northwest and southeast, or in general at about right angles to the flow of the ice; while on the coast of Maine the strikes are more nearly north and south, while the run of the ice is nearer to the meridional line than on this part of the Massachusetts shore. It is clear that the fiords are more easily formed where the strike of the strata coincides with the run of the ice than when these strikes run in the opposite condition.

The fiord structure of Cape Ann is in nowise due to the action of the sea, though these re-entrants have, as we shall shortly see, an important influence on marine action. The fiords of Cape Ann are probably due in part to ordinary fluviatile erosion acting upon rocks according to their resistance and in part to the wearing action of the ice sheet.

SEA BEACHES.

The effect of the above-described bays is to afford a place of deposit for the material worn from the headlands or brought in from the sea. The structure of one of these beaches is indicated in Plate LVII. On the coast line of Cape Ann and the neighboring mainland included within this report there are about twenty-five of these re-entrants in which beach deposits composed of materials derived from marine action have been accumulated. On the average there is one such pocket to about each mile of shore, and on no part of the marine front do we find these accumulations absent for more than two miles.

The manifest effect of these beach accumulations is in an important manner to limit the erosive work done by the pebbles under the influence of the waves. If a pebble or bowlder is retained on the cliff front until it is ground to powder, all its resistance to the blows is turned to account by the waves in the work of wearing the cliffs; as soon as it is impounded in the beach, it ceases to have any value as an erosive agent. Although it may be ground to powder upon the beach, its force is expended upon the neighboring peb-



DECOMPOSITION BOWLDER IN PLACE, LANESVILLE GRANITE COMPANY'S QUARRY, EASTERN SIDE.

SHORE AT PIGEON COVE, SHOWING EFFECT OF NEARLY HORIZONTAL JOINT PLANES WHEN WORN BY SEA WAVES; LOOKING NORTHEAST.

(The fragments at the top of the slope have been thrown up by the waves.)

bles and not upon the cliffs from which it may have been derived. The difference in the amount of erosion brought about by this variety in the history of a pebble is of considerable importance in the economy of the shore. So numerous are these pocket beaches on Cape Ann, that in most cases the masses of rock derived from the erosion of the cliffs remain for but a short time available as instruments of wear when hurled by the waves; they quickly find their way into the nearest pocket beach. (See Pl. LVII.)

The peculiar salience of the island of Cape Ann favors this rapid impounding of the pebbles. The waves run with considerable energy from a great variety of directions. They are effective on all points from the northwest around by the east to the southwest. Thus, if a pebble is held against a shore having a north and south direction by all the winds blowing from the east, the waves running during the northeast and southeast storms will tend to work it along the coast towards the nearest pocket beach. The result of this action is that the pocket beaches of the Cape Ann district contain a very much larger amount of detrital matter than has been eroded from the cliffs since the sea assumed its present altitude, much being brought from the regions north and south of the district.

EFFECT OF SEA-WEEDS ON MOVEMENTS OF PEBBLES.

The large amount of the accumulations of impounded matter in the various bays is due in part to the fact that a considerable quantity of glacial detritus has been brought in in the form of pebbles or bowlders, not exceeding a foot or so in diameter, from the deposits of such materials lying upon the sea floor. These deposits, accumulated on the sea bottom, were formed in the main during the time when the shore was at a higher level than at present. At first I was disposed to consider that the material worked in from the sea altogether, because of the fact that the recent elevation had brought the bottom so near the surface that the waves eroded the floor over which they traveled and moved the waste in towards the shore. More careful study has satisfied me that this scouring action of the waves acts only upon the sand and perhaps on pebbly matter less than an inch in diameter. The large ingress of pebbles and small bowlders must be explained in another manner.

The sandy accumulations, particularly the extensive deposits formed in Sandy Bay, on Long Beach, around Little Good Harbor beach, Brace's Cove, and other points of the shore, are clearly due to the scouring action of the waves operating on the neighboring parts of the sea floor. The pebbles, at least those above an inch in diameter, are in the main brought to the coast line in a manner which I will now describe.

The bowlders and larger pebbles, as they lie upon the sea bottom, not only by their weight oppose the movement of the waves which

tend to urge them towards the shore, but they are attached to the bottom by the adhesion naturally resulting from long continuance in their place. Even where the waves are strong enough to roll them if they were free from these attachments they remain immovable. It is to the growth of sea-weed upon their upper surfaces that we owe in most cases their detachment from the bottom and their ready transportation to the shores. When the sea-weed becomes attached to these pebbles its continued growth leads in time to the separation of the pebble from the bottom. This is brought about partly by the impulse to float due to the relative lightness of the plants, and in a larger measure through the pull which the waves are enabled to make on the expanded fronds of the sea-weed. When, in time, through the growth of the plant, this pull becomes strong enough to detach a pebble from its ancient fastenings, it rises a little way above the bottom, sometimes floats freely, sometimes just rests on the sea floor, and so impelled by the waves begins the journey towards the shore, which becomes more rapid the shallower the water to which it attains. Finally, it is brought into the mill of the surf; it then in most cases becomes separated from the plants which brought it ashore and appears as an ordinary pebble upon the beach.

Choosing a time when the surf is high, we may note a great quantity of sea-weed on the beach. Each of these weeds shows in its expanded root-like base that it has recently been severed from an attachment to some rock. Occasionally we find a pebble to which the sea-weed is still clinging. These are rarely abundant, for the reason that the separation, as before noted, has usually taken place by the pounding of the surf; but at times it is possible to gather a bushel of these pebbles still attached to the sea-weed within the distance of one hundred feet of shore line. If an observer in a time of storm will follow a retreating wave outward, so that he may have an opportunity to observe the inner face of the surf wall when it rises in its steep form a moment before the overturn of the wave, he will, if quick-eyed, be able to note in the transparent water many of these sea-weeds as they are lifted to a vertical position by the uprising of the wave. Furthermore, if he will journey in a boat beyond the surf line, he may find many of these sea-weeds floating with the tops at the surface of the water, each bearing at the base a pebble or large shell, which have been plucked from the bottom some distance from the coast line.

Although the quantity of this pebbly matter brought in by any one storm is not very great, the contribution is repeatedly made, so that during each year perhaps in a score of storms some tons of bowlder material comes upon the shore within the length of a thousand feet. A portion of these bowlders with their floats of sea-weed are of course driven against the cliff portion of the shore, where the

WORN-OUT DIKE ON SHORE OF PIGEON COVE, SO-CALLED "CHAPIN'S GULLY;" LOOKING SOUTHEAST.

SEA-CAVE ON SHORE OPPOSITE SALT ISLAND, SHOWING PROCESS OF WAVE EXCAVATION ON JOINTED ROCKS.

bowlders serve for a time in the work of the waves, but they shortly find their way into the re-entrants in the manner before described.

Not only do these sea-weed-borne fragments contribute much, perhaps a greater part, of the waste to the beaches, but in certain cases they form considerable pebbly islands off the coast. Thus, Milk Island, south of Thatcher's Island, though its central parts are of bed rock, is mainly composed of these pebbles, removed from their bedding by the sea-weed and intercepted on their journey towards the mainland by the shoal formed by this glacially rounded mass interposed in their path.

RATE OF WEAR OF PEBBLES.

The rate at which the beach pebbles wear varies of course with their size and with reference to the conditions of exposure to the surge. The smaller the pebbles, the more rapidly they are worn, for the reason that they are more readily stirred by the action of slight waves. Thus, pebbles two inches in diameter are set in motion even when the sea is nearly calm, while those a foot in diameter are probably not in motion for more than one-half of the year, and those which exceed two feet in diameter are only knocked about in the greater storms. We must reckon on the fact that the larger pebbles strike harder blows than those of small size, but I am inclined to think that the rate of wear between those one foot and one inch in diameter is generally proportionate to the difference in the mass.

It is interesting to note that no considerable part of the mud produced by the wearing of the pebbles on these beaches remains visible. By far the greater portion is evidently drawn away into the depths of the sea by the undertow which during high winds prevails along every shore.

The wearing action even on the larger pebbles is evident from observations which can readily be made on the masses of riprap used for the defense of the moles which inclose the small artificial harbors between Rockport and Pigeon Cove. Although originally of very angular forms, such as plentifully occur in the quarries, an exposure to the full beating of the waves serves even in a single year to bring about a considerable rounding of the mass. In ten years they commonly wear away to the rolled form so familiar in our beach pebbles. Under favorable circumstances it is evident that the wear upon the pebbles amounts on the average to several inches per annum. We thus obtain a rough measure of the rate at which the surges are able to bring about the wear and consequent rounding of detached masses.

It should be remarked, however, in this connection that the rate at which these artificially exposed angular masses become rounded is somewhat greater than that which occurs in masses detached from cliffs, for the reason that under the conditions in which they are

placed the sea has a peculiarly favorable opportunity for attacking them. Their position is extremely exposed, and many fragments are associated together in a manner which causes them to rub against each other more energetically than is possible at the foot of an ordinary cliff.

In seeking to find stone suitable for quarrying purposes, explorers have opened small excavations on most all the headlands around the periphery of Cape Ann. These have discharged into the sea a large quantity of angular blocks, which have been moved along the escarpments until impounded in some beach pocket, where they are now in the process of rapid erosion. Blocks of this nature can be readily separated by the eye from those which have been ruptured from the cliffs by the action of the waves and frost, for the reason that bowlders formed entirely in the natural way are generally discolored by decay to a greater depth than corrosion has penetrated, while those formed in an artificial manner usually retain the blue-gray hue of the ordinary quarry stones.

Using this means of discrimination in order to separate the artificial from the natural pebbles, the observer can readily make an eye-estimate as to the relative amounts of bowldery matter formed by natural and artificial means. He will perceive that the amount of detrital material formed in the natural way on rocky shores is often less considerable than that contributed by the process of quarrying. A number of little pocket beaches filled with bowlders which are found along the coast, especially between Loblolly Cove and Halibut Point, are almost entirely composed of rounded waste from the quarries.

The ineffectiveness of marine action on certain parts of the shore is particularly conspicuous. Thus near Pigeon Cove (See Pl. LII) it is evident that marine action has since the Glacial Period not removed in average thickness more than one or two feet of the rock which forms the shore line, while in the region immediately south of Bass Rocks the erosion is perhaps thirty times as great. The cause of this variety in the amount of wearing is readily found in the difference of original inclinations of the shore towards the sea. At Anderson Point the rocks have a very gentle slope towards the waves. The surges working on the coast line slip up over this slope and expend their energy in lifting the mass of water above its base. Where, as at Bass Rocks, the shore meets the sea at a steeper angle, the direct blow of the waves is struck against the cliffs and operates much more effectively.

The concomitant in this action is found in the extent to which the shore at these diverse points is affected by dikes which are readily worn out by the water. Near Bass Rocks and also near Straitsmouth Island the dikes are numerous and readily attacked by the waves. (See Pls. XXXIII, LIII, LV, LVI.) When the dike material is re-

CHASM ABOVE HIGH-WATER MARK, FORMED BY EROSION OF DIKE, ROCKPORT POINT, EAST SIDE.

moved steep cliffs are left on either side in positions to be open to the assault of the sea. This effect is well seen on the shores just inside of Straitsmouth Island, known as Gully Point, where the dikes, being rather softer than elsewhere, have been deeply excavated by the waves.

DECAY IN ROCKS IN PLACE.

I have already noted the fact that the bowlders contained in the frontal moraines are in many cases extensively decayed. So far has this decay gone, that I have often found a bowlder which was originally six feet in diameter represented by a low mound of angular sand upon which the vegetation finds root. The same decay, though in much less striking form, is exhibited by the rocks in place. So far as my observations have gone this decay is limited to the granitites, not affecting the dike stones. It generally occurs within 10 feet of the surface in sections where the rocks lie in a position which favors the penetration of surface water. Finding its way along the joints, the water furnishes conditions of corrosion, so that from the joint planes the decay penetrates to a greater or less distance into the unrifted portion between the fracture planes. A portion of the material is reduced to the state of sand, another part is merely discolored and weakened by the oxidizing process. (See Pl. LI.)

In passing, I may remark the fact that the considerable penetration of this form of decay since the Glacial Period affords, when taken in connection with the decayed bowlders above referred to, important evidence as to the depth to which the glacial erosion operated during the last ice time. It is evident that the decayed bowlders were not affected by the corrosive process before they entered on their journey towards the front of the ice field. The strains to which they were subjected in that journey would have led to their destruction if they had not been of very solid rock. In order to obtain bowldery matter liable to corrosion and at the same time not decayed, the glaciers must have removed all the superficial parts of oxidized rocks which existed on the surface at the time their work began.

There can be no question that the decay in certain of the bowlders is generally more complete than that which has occurred in any rock in place. This is readily explained by the fact that the bowlders are much more favorably placed for the work of corrosion than are any portions of the rocks in their original position.

RECENT CHANGES OF LEVEL IN THE CAPE ANN DISTRICT.

As one of the principal objects of the series of monographs descriptive of different parts of the Atlantic coast which I have undertaken is to determine the recent changes of level which have occurred along that shore line, I turn with interest to the study of

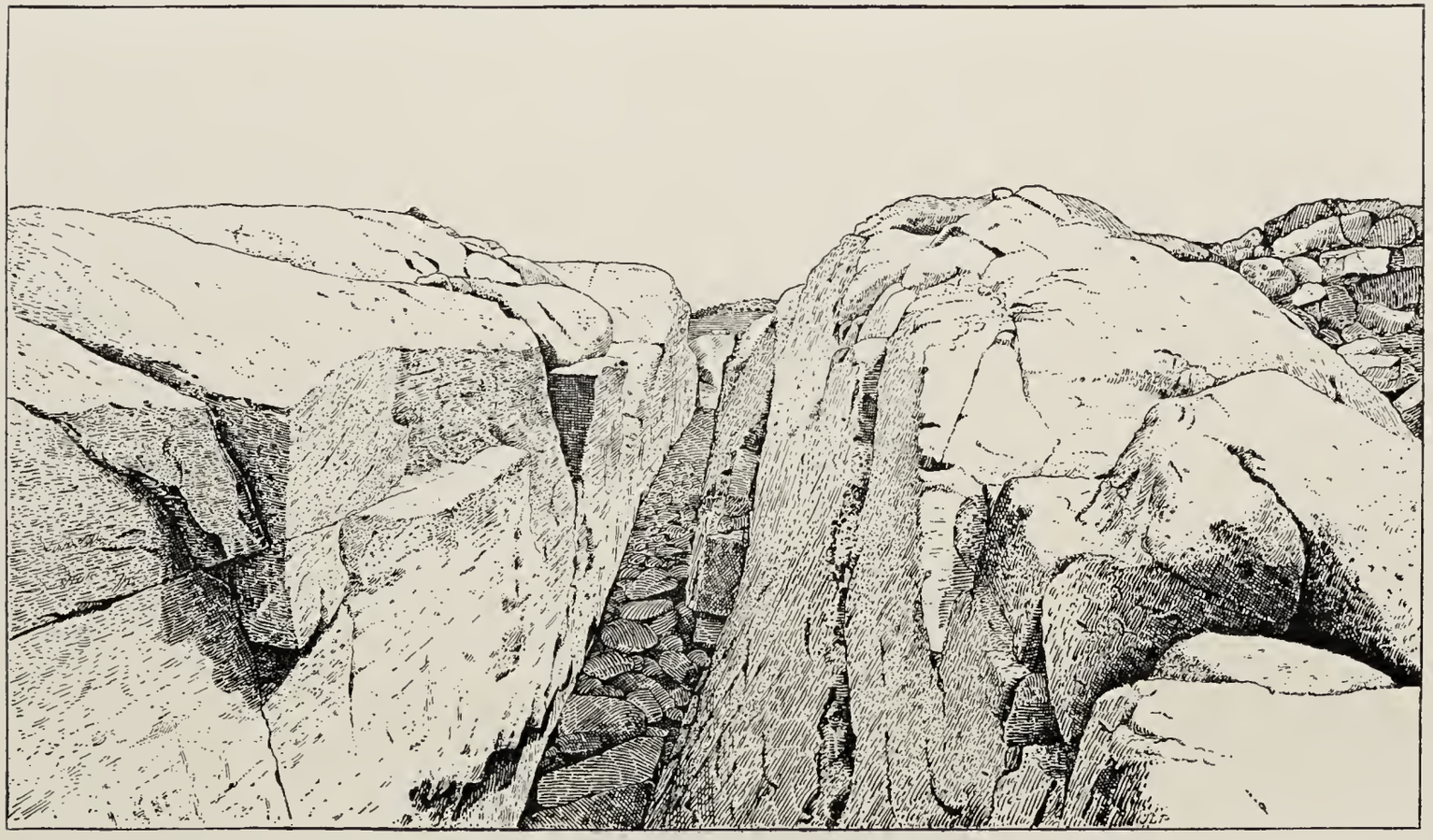
post-glacial changes in the altitude of the land on this part of the coast.

My studies on the island of Mount Desert have apparently shown that on that shore, one hundred miles north of Cape Ann, very remarkable alterations of level have taken place since the close of the Glacial Period, or at least since the disappearance of the ice sheet from that portion of the coast. On Mount Desert the evidence indicates movements of elevation since the disappearance of the ice, and on other parts of the shore from Portland southward the evidence is to the effect that the movements have been in part in the direction of subsidence and in part those of elevation. On Mount Desert itself all the observed facts indicate elevation alone, though, as remarked in my memoir on that island, published in the Annual Report of the Director for 1886–'87, the shore of Mount Desert is very unfavorably placed for the preservation of evidence of subsidence. It may therefore well be the case that subsidence has taken place there, though the proof of it is wanting.

EVIDENCES OF RECENT SUBSIDENCE.

Considering first the evidence of recent subsidence, we find on Cape Ann a limited but important set of facts which bear on this problem. On the east shore of the island, at a point indicated on the map by the words "submerged forest," near the isolated mass of rock known as "Briar Neck," we find between high and low tide mark a number of tree stumps with their roots still fixed in an ancient soil in their normal positions, which clearly indicate a very recent subsidence, amounting to as much as four feet of actual height. These interesting remains lie in a position that appears to me to exclude any other hypothesis than that which assumes that the surface on which they stand has been lowered by a downward movement of the subjacent earth. They stand upon a nearly plane surface, in front of a low beach wall of sand and pebbles; behind them lies a considerable area of marine marshes.

In this and the numerous other cases of depressed forests which occur on our shore the hypothesis which has been suggested, that the sea has undercut the soil in which the forest grew, thus lowering it beneath its present position, appears to me quite untenable. The waves strike against this shore with great energy. As soon as the stumps are separated from the enveloping beach sand they are quickly cut away by the surf. The process of undercutting which should lower the forest bed to the level of the waves would necessarily lead to the immediate destruction of the deposit. Moreover, here as elsewhere, we ask the question as to where we may now find this process of undercutting in operation? If we account for the submerged forests on this theory, we should be prepared to show



DIKE CHASM ABOVE HIGH-WATER MARK, WEST SIDE OF ROCKPORT POINT, SHOWING DIKE MATERIAL CONVERTED INTO BOWLDERS.

along our extensive shore line instances in which it may be seen in various stages of accomplishment. My studies on the Atlantic shore line have shown me in a very detailed way the greater part of the coast between Eastport and New York. At no point have I ever observed any process of undercutting the forest such as this hypothesis demands. I therefore take this example as well as the numerous others which occur along our coast as complete evidence that a recent subsidence of the shore or elevation of the sea to the amount of several feet has occurred in very modern times.[1]

So far this is the only instance on the periphery of Cape Ann where I have been able certainly to ascertain the existence of submerged forests. It is to be observed that the conditions which permit the preservation and the re-elevation of such deposits are peculiar. Except where shown by artificial excavations, we find them at points where the sea cuts through a mass of dune sand such as forms along the coast line or sand of the beach, in which the remains of the forest lie buried. Where a beach is gaining on the sea, as is the case with most of the sand beaches of the Cape Ann district, we can not of course expect to gain any sight of a submerged forest existing at that point. It is only where the sand beaches are retreating landward that the buried forests are likely to be exposed to view.

Although the existing remains of the submerged forests above referred to prove at most a subsidence of four or five feet, there is good reason to believe that the total amount of this depression has been much greater than is indicated at this place. In the adjacent waters of Massachusetts Bay we find on the flats of Lynn Bay occasional stumps of trees faintly exposed to view through the water at the lowest run of the tides, and in Cambridgeport, Mass., I obtained the stump of a tree in position seventeen feet below high-tide mark, or about seven feet below the lowest tides of the present day.

EVIDENCES OF RECENT ELEVATION.

The evidences of recent elevation along the coast of Cape Ann are extremely obscure, at least when compared with the proof of such movements afforded on the island of Mount Desert. The proofs which we may obtain of the temporary sojourn of the sea at heights above its present level fall into the following classes: First, we may have a surface swept clear of all but the larger bowlders in the fashion shown along the present shore line. This effect may be looked for even where the sea operated on the surface for a very brief time, provided the drift coating was not extremely thick. Where the surface has been scoured in this fashion by the waves the drift is not only removed from the convex portions of the area, but is

[1] See memoir on Martha's Vineyard, Annual Report U. S. Geol. Survey for 1885–'86; also report on Geology of Nantucket, Bulletin of Geological Survey, No. 53.

scoured out of the crevices and clefts of the rock, in which it is sure to remain where the waves have not washed their surfaces. Thus, such rock areas as are shown in Pls. XXXIII, XXXIV, LVIII, LIX, LX, LXI, and Fig. 45, clearly indicate the action of the waves by the complete removal of the detrital material which has accumulated at their base in the form of a gently sloping talus.

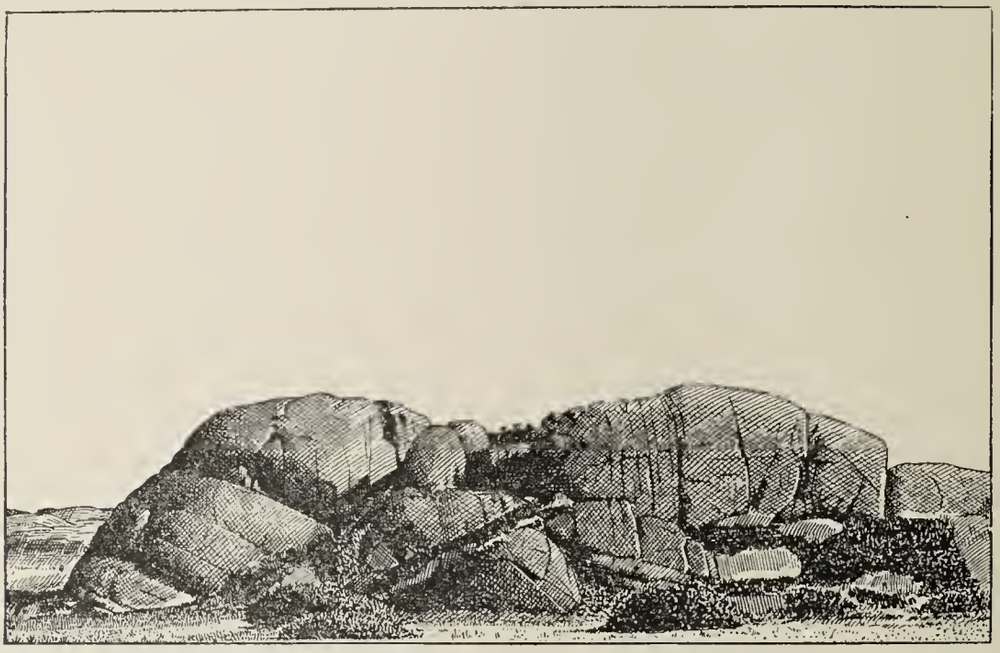


FIG. 44. Eastern Point, 40 to 70 feet above sea; ledges from which drift has been completely removed by marine action.

Where the waves operated for a considerable time on the surface, we may expect to find the softer parts of the rocks, the portions enfeebled by the numerous joints or by dikes, distinctly excavated, forming chasms or sea caves according to the direction in which the lines of weakness extend. The amount of this distinct cutting action depends largely on the slope of the rocky surface ; as we see along the existing shore where this slope is very gentle the sea has practically no cutting power, whereas if the original slope was steep, the cliff and bench, such as shown in Pl. XXXIII, quickly formed. Again, where the process of erosion has continued for a considerable time the waste removed from the salients will be accumulated in the form of beaches in the interior portion of the re-entrant angles. The accumulation of beaches appears to require a more continued action of the sea than is needed for the formation of the other indices of marine action.

It is important to notice that where the drift coating is thick the natural processes which affect the movements of the soil after the passage of the sea from the surface at once operate to destroy all marks of wave action upon the surface. Although a scarf may be cut in the detrital matter, and perhaps in the solid rock upon which

NORTHEAST END OF BEACH NEAR CAPE HEDGE, MILK ISLAND IN DISTANCE, SHOWING TYPE OF BOWLDER BEACH.

it rests, no sooner does the sea disappear than gravity, aided by the action of frost and by the action of trees which by their expanding roots shove the masses downwards and in the cases where the trunks are overturned by winds displace large masses of the material, serves quickly to heal the slope, so that in a short time the bench may be entirely effaced. This action is so manifest on the surface of Mount Desert that I have long since ceased to put much trust in indications of marine action derived from faces of loose material, though it can not be denied that traces of such erosion may be found on the flanks of some of our drumlins.

HEIGHT OF SEA SINCE GLACIAL PERIOD.

The imperfect evidence which I have succeeded in obtaining on the Cape Ann district, serving to show the action of the sea above its present level, is limited to 150 feet above the present tide mark. Within this section the evidence consists mainly in the removal of the drift from extensive areas of rock on which it was originally thinly distributed.

Where, on a large area, we find no glacial debris except occasional bowlders with the dimensions of those which now resist the action of the waves along the shore, we may be pretty sure that the sea has not acted, and this for the following reason, viz: On any surface which has been glacially eroded, as has the whole of the Cape Ann district, the ice as it passed away must have left a thin sheet of detrital materials. Even where the surface was more or less washed by the melting waters of the retreating ice, the crannies and hollow places of the rock surfaces would necessarily contain a good deal of glacial waste which would escape removal. I am unable to explain a complete scouring of the surface, such as is exhibited in Pls. LIV and LIX, without having recourse to wave action.

The argument in favor of wave action becomes stronger when, as before remarked, we find the steeper faces of the rocks worn by the work of the sea in the fashion that can be effected only by the battering action of the surges. It is usually easy in case of any strongly projecting mass of glacially eroded bed rock to determine which of its several versants would have received the direct beating of the waves and which would have been protected from their action. If, on the faces which would have been exposed to the ocean surges at the time when the sea is supposed to have stood at the higher level, we find a recognizable amount of marine erosion, we substantiate the hypothesis which supposes the original greater height of the sea.

Beginning at the present level of the sea, we first note the fact that the recent slight uplift has raised the shore to the amount of something less than ten feet. This is shown by the conditions prevailing in many of the clefts along the shore which have evidently been eroded by wave action, though the principal parts of ascending

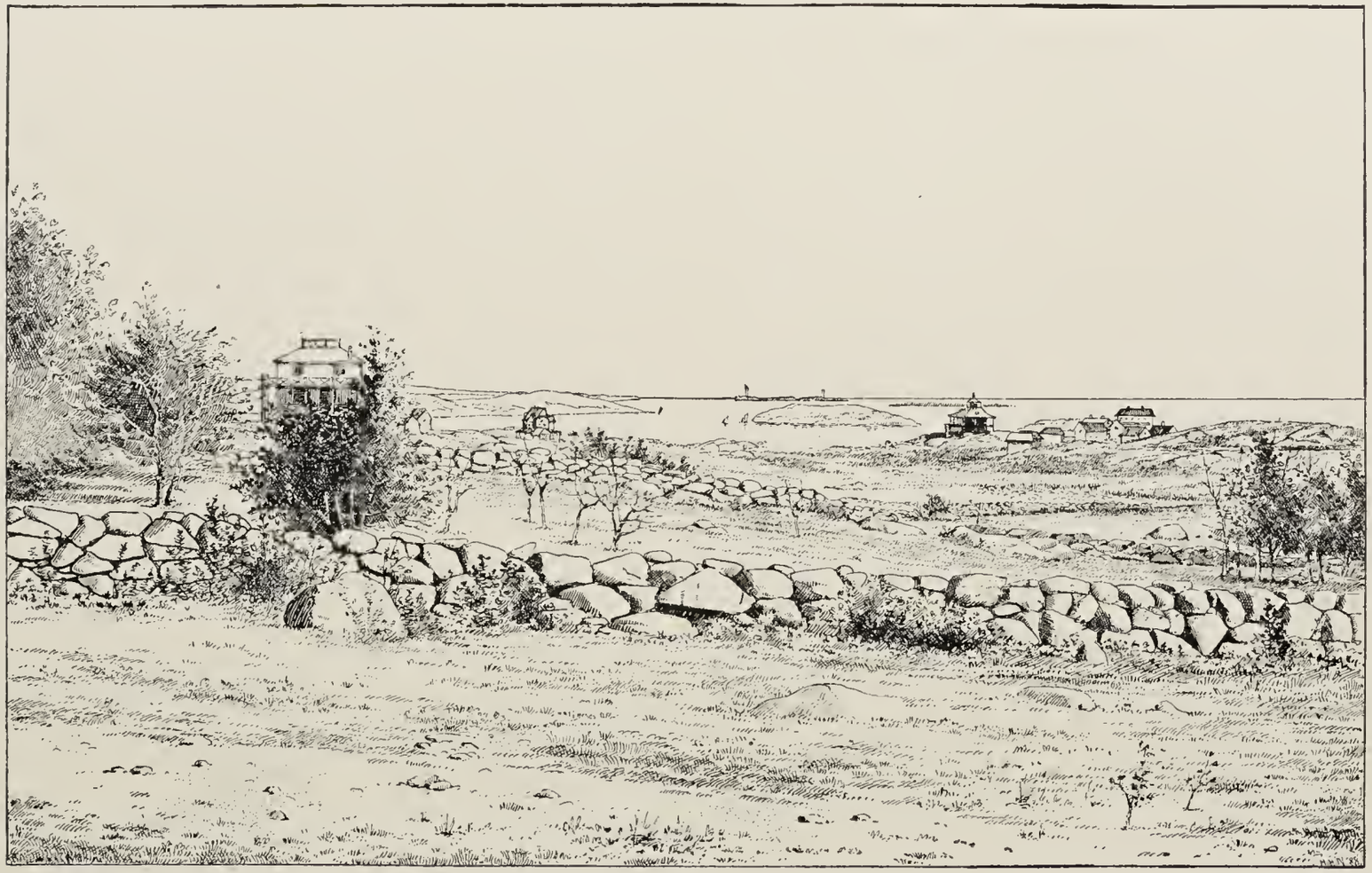
floors are at present sufficiently above the existing plane of the sea. Thus in Pl. LXII we see an example of the cases of chasms which are evidently due to wave action, but which have parts of their beds now much above the water level. Furthermore, it appears evident at various points on the shore, as is exhibited in Fig. 45 and Pl. LXI that the rock surface has been swept by waves when the sea had access to somewhat higher points than it has at present.

At first sight I was disposed to attribute this difference in the action of the waves to the gradual shoaling of the water of the coast and the consequent failure of the waves to attain the shore when they were operating with their utmost energy. A careful consideration of the facts, however, has satisfied me that this is not a sufficient explanation of the phenomena, for the reason that the evidence of uprising is conspicuous even on those parts of the shore where in the heaviest storms the waves do not break until they touch the shore line. Thus in the case of the excavated dike on the east side of Gloucester harbor, shown in Pl. LXII, the waves never have any great energy and yet they have clearly operated to excavate the dike to a height of about ten feet above the level at which they at present operate.

Passing upwards, we find the next level on which marine action is indicated at a height of about forty feet above the present high tide and thence upward to the height of about seventy feet. The operation of the sea at this height is more or less plainly shown around the whole of the periphery of Cape Ann, wherever the surfaces are well fitted to retain indications of marine action. Thus in Fig. 45, on the east shore of Gloucester harbor we note a portion of an extensive field which has been thoroughly washed by wave action and the crannies cleared of all save a few tightly wedged bowlders and the lines of weakness to a certain extent developed in the form of sea caves and clefts.

The next level exhibiting distinct marine erosion is at the height of from about one hundred to one hundred and thirty feet. The indications of marine action at this height are more distinct upon the eastern and southern portions of the island than upon other parts, for the reason that the rocks stand in more favorable positions for the exposition of such action and they are less thickly covered by a drift coating which might, as before suggested, conceal the effects of the waves. Above the height of 130 feet nearly the whole of the island is thickly covered with the morainal matter. The extreme instability of the slopes cut in this material is well shown by the constant movement of the detritus where it is exposed at steep slopes in existing railway cuts. A few thousand years of exposure, especially if the surface becomes subjected to the action of strong roots and the overturning of trees, would clearly serve to efface marine scarfs or other evidences of shore-line action.

The very fact that morainal drift on this island is mainly limited



VIEW NEAR BASS ROCKS—SALT ISLAND, MILK ISLAND, AND THATCHER'S ISLAND IN THE DISTANCE—SHOWING GENERAL CHARACTER OF SURFACE; HALF BARE ROCK, HALF TILL.

to heights above 100 feet is of itself evidence of a certain value to show the action of the sea. (See Pl. LXXV.) There is no other way in which we can so well account for the limitation in distribution of this drift as by the supposition that it has been worn away at lower levels by marine action, taking effect in the form of waves or of shore ice.

Below the general surface of rocks apparently wave swept, between the present level of the sea and the height of 140 feet, we almost invariably find a gently inclined talus, composed of materials which, we may presume, have been swept from the bared surfaces. Wherever we are enabled to get any section of this detrital matter it appears to be rudely stratified, much as the waste which has lately been stripped from the shore line is laid down at the foot of the sea cliffs.

At first sight the observer may be surprised to find that these taluses have not their upper edge at a regular height above the level of the sea; in other words, they are not beaches formed at the foot of cliffs but under-water taluses, having only a partial likeness to the beach structures. If he will observe the existing shore line with the plummet to determine the depth of the taluses below sea water he will find that they exhibit an irregularity like that which we find at higher levels where we have assumed that the sea operated.

The only difficulty which we encounter in supposing that the phenomena in question are to be explained by marine action at higher levels is due to the fact that we fail to find distinct beaches of characteristic shape lying in positions corresponding to those they now occupy at lower levels. So far I have been unable to trace any unquestionable beaches which were formed during the time when the sea should have occupied the higher levels where I am disposed to believe it has been. The failure to find these structures is certainly an argument against a long continued action of the sea at any point above its present height. A careful study, however, has convinced me that beaches are not quickly or rapidly formed by marine action, but they represent the slow operation of forces which can come into action only under peculiar circumstances. Replacing the sea along this shore at the height of 100 feet in imagination, we note that the considerable depth of water of that shore line would make it impossible for the waves to come into possession of any large amount of detritus. The fine matter in moraines is relatively small in quantity, and the large bowlders are hard to move in the manner necessary to form beaches. All save the largest of them would quickly be dragged into the troughs of the shore, but it would evidently require a considerable time for the formation of any distinct beaches in the reentrants. At present a greater part of the pebbles which are found on such beaches are brought in by the action of marine plants, which, presumably, did not exist along this shore in the closing stages of the ice time. The sands of the sand beaches are heaved in from the

seaward, owing to the fact that the water in the existing condition of the levels is tolerably shallow. With 100 feet added to the depth, they would be as completely wanting as they now are on many parts of the coast of Maine. It is only the beaches composed of large rounded pebbles, exceeding six inches in diameter, which we could expect to find along the shore line when it was at higher levels, and such accumulations never have the characteristic form of ordinary beaches.

There are many points about Boston where artificial scarfs such as those made by roads have been formed on slopes of drift materials and allowed by the abandonment of the way to return to a state of nature. Studying such localities, we observe that the action of frost and rain serves in the course of a score or two of years to destroy most of the superficial indications of such an excavation. Even after twenty years, in the case of scarfs which have been exposed in a steep wall three or four feet high, the effect of the cutting is very faintly indicated. It is impossible that such indentations would survive the processes of nature for as much as a thousand years on an ordinary surface. It is a noteworthy fact that on Mount Desert, where as noted in my report (loc. cit.) the old sea levels though distinctly indicated by excavations in the jointed granitic rocks, are rarely manifested in the detrital materials, only at altitudes within 100 feet of the sea level and in places where the detrital materials are more abundant than at any point on Cape Ann, do we find the marine action manifested in the form of beaches. Thus, on the periphery of Mount Desert, which has an extent of from 50 to 60 miles, there are but two places in all the ancient shore lines, having together a length of less than half a mile, where it is possible to determine the existence of sea-worn gravels disposed in their characteristic form. So it is hardly a matter of surprise that we should fail to find them on the much smaller area of Cape Ann, where the detrital matter is less suited to form beaches. Therefore, in endeavoring to ascertain the former presence of the sea at higher levels, I have relied upon the evidences of the scouring action of the waves and the indentations which they have produced on the bed rocks rather than upon the action exhibited by detrital materials.

DUNES OF CAPE ANN DISTRICT.

We may here note certain interesting features connected with the dune deposits which occur in the Cape Ann district. This portion of the shore of New England is interesting for the reason that it is one of the northernmost points at which extensive duning occurs, it being part of a field occupied by deposits of this nature extending from the northern point of Cape Ann to Portsmouth, N. H. (See Pl. LXIII). On the island of Cape Ann the most important dunes occur on the north shore and upon the east face of the island near

DIKES CUTTING HORNBLENDIC GRANITITE; BASS ROCKS.

Long Beach. Those near Long Beach belong to the ordinary category of shore dunes, which are in the process of growth at the present time.

On the north shore of that island we have a series of these dune deposits extending from near Halibut Point to Annisquam harbor, which are particularly interesting for the reason that they are evidently due to some conditions which are not in operation at present. All these dunes on the northern face of the island have long been grassed, and there is no indication that sand is now coming ashore in sufficient quantities to produce deposits of this nature. The water of the north shore is so deep that only very small amounts of sandy matter are from time to time scoured up among the rocks, yet it is evident that in a recent period the amount of sand yielded to the wind was large. The only way in which I can explain this peculiar feature is by supposing that at a time before the last subsidence, indicated by the submerged forest before described, this north shore was sufficiently elevated to afford sand beaches along the coast from which these dune sands have been swept inland.

In passing I may remark that the singular occurrence of what appear to be dune sands at various points remote from the present coast in Massachusetts and Rhode Island may perhaps be explained by the former presence of the sea at higher levels along the shore. On the mainland opposite Annisquam village, the point known as Coffin's Beach, there are very extensive dune deposits which are in the process of active construction. There is a tradition to the effect that two small farms which were tilled during the last century have been overwhelmed by the southern march of these sands. The genesis of these dunes is easily to be understood. The shore from Coffin's Beach to Newburyport trends in a general northwest direction, the whole of this coast constituting a great pocket beach on which the sands tend to move southwardly under the influence of the waves, their further southward journey being hindered by the salient of Cape Ann. The wind frequently blows in dry periods from the northwest and sweeps the beach sands southward to the bottom of the recess and accumulates them in these dune hills. It is likely that the southward movement of these sands was greater in the period of elevation just referred to than it is at present. Despite the evidence of the tradition which goes to show that these sands have recently advanced to the south, I am of the opinion that the accumulation of the deposit mostly took place in ancient times.

MARSHES.

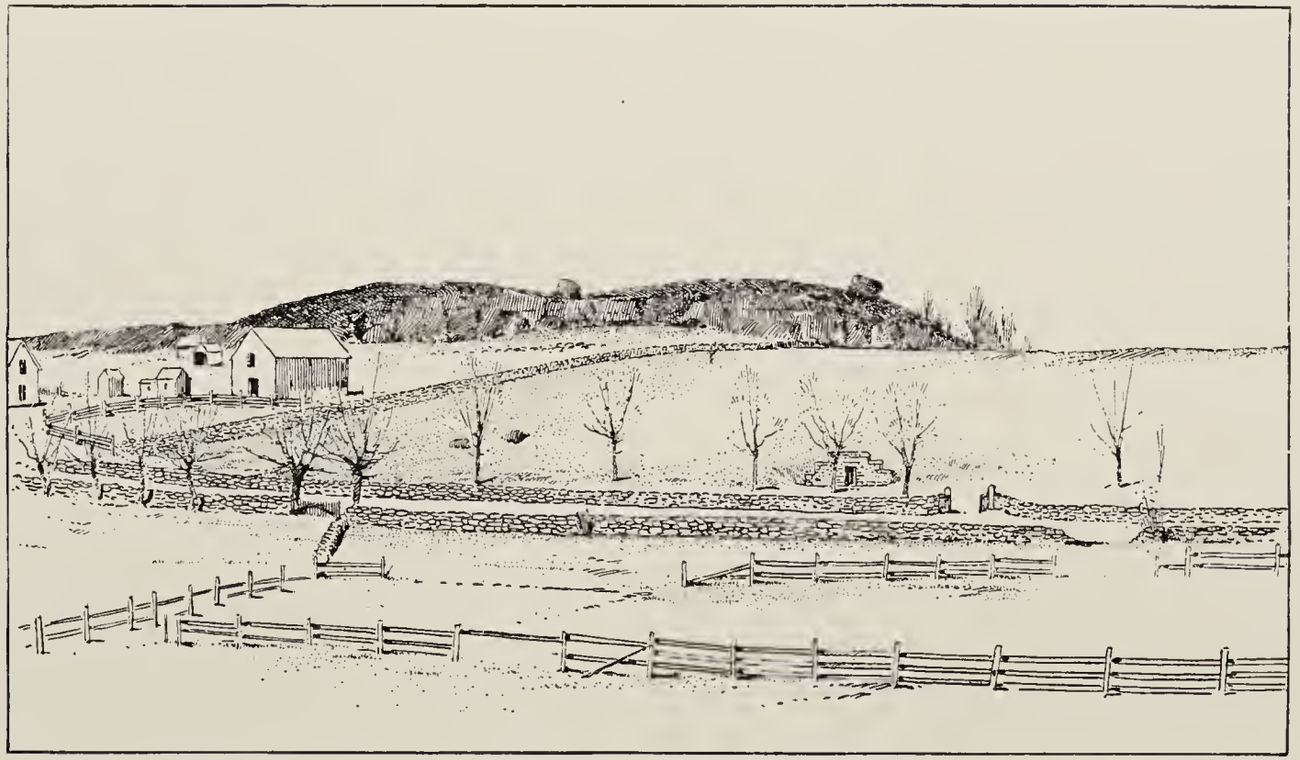
The marshes of Cape Ann occupy but a limited area. They are divisible into three groups, fresh water deposits of the uplands, fresh water deposits formed behind walled beaches, and true tidal marshes. The upland morasses are all of small area and with the

exception of a few deposits made in kame pits they lie altogether in irregularities of the ground or frontal moraines or in the numerous rock basins which beset the surface of the island. None of these areas appear to be drainable and they are therefore of no economic importance. The marshes impounded by beach walls are also of small extent, only one being of sufficient area for discussion. These lie on the shore between Brier's Neck and Bass Rocks. There is here an area of one hundred acres or more, the drainage of which is affected by the access of the tide and a portion of the field is ordinary salt marsh. By closing out the salt water by dams, with considerable exits for the inland waters, an important area can be reclaimed at this point. On Squam River, a considerable fiord which separates the island of Cape Ann from the main, there is a total area of about one hundred acres of reclaimable salt marsh. Unfortunately, a large part of this area is of a sandy nature. The sands which have worked down the shore from the northwest and which have formed in part the dunes of Coffin's Beach have poured into this basin and affected the character of the marshes as far south as Pearce's Island. Nevertheless, these marshes appear to me to be worth winning to agriculture. They can be reclaimed by very slight dams, for the reason that the waves they would face are of trifling size. Although the sand which has been contributed to these marshes will somewhat diminish their fertility, the admixture will make it easier for them to be reduced to the tillage state. Including the marshes along Little River, it appears to me likely that from 300 to 600 acres of high grade agricultural land can be won along the shores of this fiord.

PHYSICAL STRUCTURE OF THE BED ROCKS OF CAPE ANN.

One of the principal objects of this memoir is to set forth certain features connected with the crystalline rocks of Cape Ann. Nowhere along our coast are rocks of this description so well shown as here. With slight exceptions, where these materials are covered by recently formed beaches, the whole periphery of the island is exposed to view. These rocks form the root of a considerable anticline, the axis of which extends from northeast to southwest. The shore line of Cape Ann affords us by its varied outline extensive sections parallel with the trend of the anticline and across its axis. We are thus enabled to observe in a large way the nature of the accidents which took place during the movement which attended the formation of this mountain ridge.

This region is very favorably suited for the study of joint systems developed in the macro-crystalline rocks, and also for observations on a variety of dike injections which occurred at successive periods during the construction of the mountain uplift. At no other point on the east coast of the United States do we have anything like as good an opportunity to follow the dynamic history of the lower por-



PERCHED BOWLDER RESTING ON BARE GRANITE, ONE-HALF MILE NORTHWEST OF GLOUCESTER STATION; TAKEN FROM A POINT NEAR THE MAIN ROAD TO ANNISQUAM.

tion of an extensive anticline. In the interior districts of the country there are many points at which erosion has in a measure disclosed the substructure of great mountain arches; but so far as is known to me there is no case in which this structure is not very much masked by accumulations of soil or rubbly material. At this point the action of the sea has given us a remarkably clear horizontal section many miles in extent.

The disclosure of this anticline which the sea has afforded extends somewhat beyond the limits of Cape Ann. It begins on the southwest at Lynn and extends along the shore through Swampscott, Marblehead, Beverly, Manchester, and Magnolia, to Cape Ann. Although it is intersected at Cape Ann by the fiord indentation of Annisquam Reach, it is essentially a part of the same geologic structure. It will therefore be necessary to extend our consideration to the shore of Massachusetts Bay as far west as Lynn. It will be particularly desirable to effect this extension for the reason that in the section southwest of Cape Ann we have the peripheral deposits of the anticline fairly well disclosed, and can see the relations of the granitites to the superjacent deposits, which belong in the anticlinal fold or lie upon the node between the up curve and down curve of the mountain arch.

West of Lynn, in the region near the southwestern extremity of Boston Bay syncline, we have an extensive series of more or less metamorphosed rocks, including the Cambridge slates, the Roxbury conglomerates, the Nahant schists, and the Braintree fossiliferous slates. These beds have an aggregate thickness of not less than 6,000 feet, and they may be of much greater depth. They occupy the whole field of the central part of the syncline. In this section there have been very extensive though irregular extrusions of volcanic rocks, rocks which appear to have been in part at least the product of subaerial volcanic action. These deposits are found in the northern part of the syncline near Lynn, Saugus, and Malden. On the south shore they occur in Hingham and Nantasket. They apparently lie in immediate contact with the granitic series which compose the mass of the anticline, and were probably formed after these highly crystalline rocks took on their character and assumed their present relations to the mountain arch.

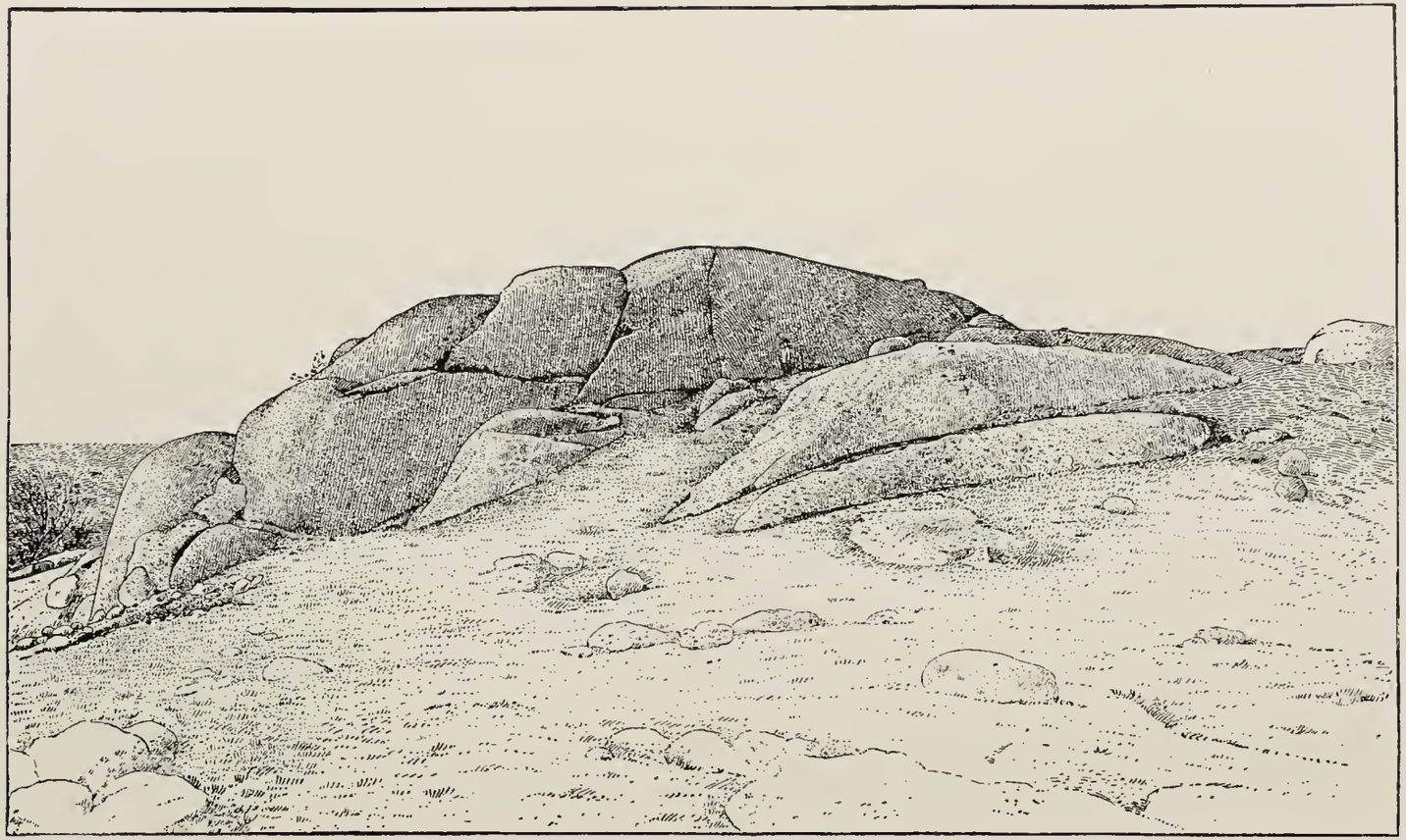
There can be little doubt that a large part of the beds which occupy the central portion of the syncline was deposited before the uplift of the anticlinal axis. The Braintree series appears to have been formed in deep water at a distance from the shore. The slates of Cambridge and Somerville which probably lie at the base of the Roxbury conglomerate also seem to have formed in deep water; but the Roxbury conglomerate contains abundant fragments among its pebbles which appear to have been derived from the erosion of the anticlines which bound the basin in which it lies. Not only are the

granitites and their accompanying dikes of this anticlinal axis extensively represented, composing, indeed, in places a large part of the fragmental material, but the volcanic ejections before mentioned are also represented in these pebbles. It is also probable that a large part, if not the whole, of the Nahant series was deposited after the time when the syncline and the corresponding anticlines on the north and south had begun to develop.

Thus the general history of these mountain movements appears to have been as follows: Anterior to the orographic development of this district, it was occupied by an extensive series of deposits of unknown thickness and of early Cambrian age. Evidence which can not be given here appears to indicate that these ancient beds were considerably eroded before they were disturbed by mountain foldings; then came the formation of the anticlines, attended or followed by the volcanic outbreaks indicated by the remaining accumulations of this nature in Lynn and Nantasket districts. Afterwards, most likely in the period of the Potsdam sandstone, though perhaps at a subsequent date, came the extensive erosions from the anticlines and depositions in the syncline, which produced the Roxbury conglomerates.

This much of the history of the Boston axes is indicated by the beds which lie to the southwest of Swampscott. To the northeast of Swampscott, marine and other erosion has swept away or reduced below the ocean level all the beds which belong in the synclinal as well as those volcanic ejections which lie upon the flanks of the anticlinal, and thence outwardly to the extremity of Cape Ann we have only the roots of the old mountain axis which we are considering. From Lynn eastward the superficial deposits are almost entirely removed and exhibit the succession of crystalline rocks. At first on the west these are more or less gneissoid, and as we go east as far as Beverly they become more and more massive until we find the materials of the normal purely crystalline structure exhibited on Cape Ann. The section from Lynn to Annisquam Reach is in a general way beveled from the higher to the lower and more crystalline rocks. Although it is not possible to trace the section in detail, on account of the abundant faulting and other movements to which it has been subjected, I am inclined to think that there is a belt of gneissoid rocks, having a depth of from 1,000 to 3,000 feet, lying between the purely crystalline granites and the distinctly stratified Cambrian deposits of the syncline. In the main, the volcanic series appears to rest upon and break through these somewhat gneissic rocks.

From Lynn, where the massive crystalline rocks first come to the shore, eastward to Cape Ann, the coast line is abundantly intersected by dikes. Eastward as far as Marblehead, the larger part of these injections consist of distinctly porphyritic material. From Marblehead to Cape Ann, the proportion of this porphyritic material pro-



SUNSET ROCK, ANNISQUAM, MASSACHUSETTS, SHOWING HARD MASS ROUNDED BY GLACIATION AND STRIPPED OF ITS DEBRIS BY MARINE ACTION.

gressively diminishes and the dikes have an ordinary crystalline character becoming relatively more abundant. Along this part of the south wall of the anticline, in which the obscurely gneissic rocks find a place, the dikes are greatly disrupted. Thus, at the Preston House, near the line between the towns of Lynn and Swampscott, where there is a very extensive exposure of massive rocks that have been laid bare by the action of the sea, we find all the dikes extraordinarily ruptured by faults, and broken up in a degree never seen on Cape Ann. In general, it appears that the flanks of this anticline, in the section where the uplift of the anticline is turning to the downward flexure of the syncline, have been much more affected by disruptive movements than the central portions of the anticlinal axis which alone are represented on Cape Ann.

MINERALOGICAL CHARACTER OF ROCKS.

Within the limits of Cape Ann, saving in the case of small inclusions, all the granitic rock is of an entirely massive character. No trace of gneissoid structure has been observed in any part of that field, the fact probably being that the whole of the gneissic part of the section has been stripped away. Prolonging in a general manner the axis of such rocks as they appear on the southwest, it is readily seen that they come within a mile of the southern portion of this Cape.

Although the granites of Cape Ann vary somewhat in character in different parts of that field, at no point are the variations so far constant that any discrimination of the deposits into distinct areas, at least in the present state of our information, can be effected.

DIKES OF THE CAPE ANN DISTRICT.

One of the aims of this inquiry has been to determine the number, character, and position of dike intrusions in this district. The study of the shore line where the rocks are bared by the sea, in quarries and other artificial cuttings, has shown a total of 361 dike intrusions. Some 30 dikes which have been observed only in quarries may be identical with some which appear on the coast line, but the repetitions are not likely to diminish the total as set forth above.

The portion of the crystalline rocks of Cape Ann which is bared by the action of the sea or by artificial openings probably does not exceed a twentieth of its total area. Although there are large surfaces of bed rocks exposed to view in the interior of the island, these areas in their natural state reveal few dikes, owing to the fact that the contents of these fissures readily decay and form crevices which are filled with rubble or drift materials. Only five dikes have been determined in these natural exposures of bed rocks, though many have been suspected to exist. The distribution of dikes on the shore, the abundant waste of such injections in the drift, and the

other evidence before adduced go to show that these injections are about as numerous in the interior as they are on the coast. We may therefore reckon that the number of these intrusions within the limits of the island amounts to a much larger number than those exposed to view.

Neglecting at present the topographical character of the dikes, we find the general distribution of such fissures about as follows: Beginning with Eastern Point, we find that promontory moderately intersected with dikes to High Pebble Beach; from that point to Good Harbor Beach the number of these injections rapidly increases. At Bass Rocks they are about as abundant as at any point on the island, constituting perhaps a twenty-fifth of the visible mass. (See Pl. LIX.) They are also extremely abundant on Rocky Neck, in Gloucester harbor. From Bass Rocks to Cape Hedge the shore line is mainly occupied by beach accumulations. On the exposed portion of the shore occupied by Briar Neck inside of Salt Island the dikes are again extremely abundant. The indications derived from the interior appear to make it likely that the rocks to the west of Briar Neck are extensively cut by these injections, which mostly have a northwest and southwest extension. From Cape Hedge to Sandy Bay the number in a given extent of shore line diminishes; they are still, however, tolerably abundant. From Sandy Bay to Folly Cove they are substantially wanting, except in a small extent of shore on Halibut Point, where half a dozen occur. From Folly Cove southwestward they again become abundant and continue so to the mouth of Annisquam harbor, being most developed from Davis's Neck to the entrance of that harbor. Along the shore of Annisquam Reach from its northern mouth to Gloucester the conditions of the shore are not well suited to disclose these dikes, but the evidence seems to indicate that they abound in this portion of the section.

DISTRIBUTION OF DIKES.

The diagrammatic summaries showing the distribution of dikes give with close approximation to accuracy their distribution as regards compass directions. (Fig. 46.) It will be seen that of the 361 dikes the courses of which have been observed, including about all which are visible on the island, 266 lie in the quadrant between northwest and north, and 150 in the 25° between N. 45° W. and N. 20° W. It is thus evident that by far the greater part of the dikes, 266 out of 361, as against 95 in other parts of the circle, lie in the northwest quadrant, and more than half the total in the 45 degrees between north and northwest. The remainder of the dikes are irregularly distributed, the only considerable accumulation being in the portion of the circle between N. 30° E. and N. 60° E., where there are 44 dikes. The most remarkable concentration is that which occurs between N. 30° and N. 35° W., where in all there are 53 fis-

EAST SIDE OF GLOUCESTER HARBOR, SOUTHEAST FROM TEN-POUND ISLAND, SHOWING DIKE EXCAVATED BY SEA WHEN SHORE WAS ABOUT 10 FEET BELOW PRESENT LEVEL.

sures, or about a seventh of the total number. Thus the ratio of accumulation in these five degrees of the half circle is about as 7 to 36 in the remaining 175 degrees. As a whole the observed attitudes of these dikes show that they are far more developed in the quadrant from north to west than in the quadrant from north to east, in the ratio of 166 to 95, with, as before remarked, a singular concentration in the section between N. 30° W. and N. 35° W.

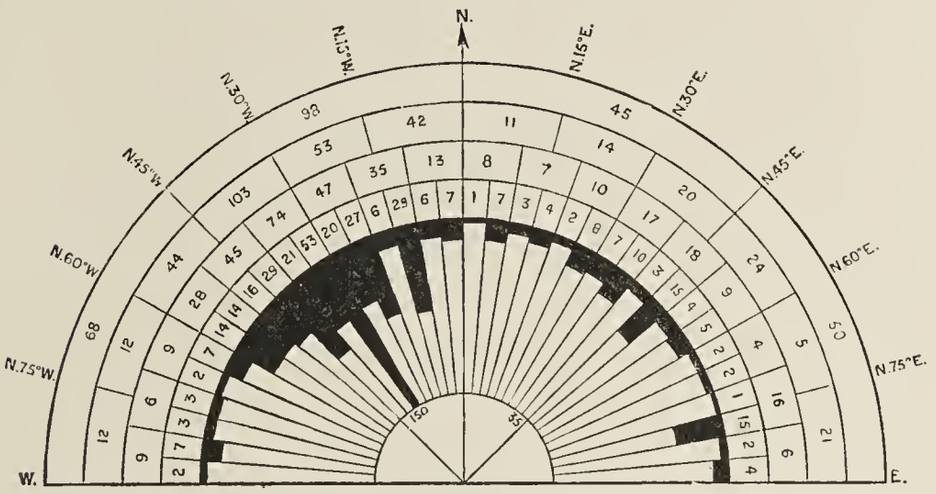


FIG. 45. Diagrammatic tabulation of strikes of dikes on the island of Cape Ann.

The appended diagram (Fig. 47) indicates the attitude of the dikes with reference to the vertical. It shows that the range in position is from 30° to 90°, with a steadfastly increasing number as we approach the vertical position. No dikes of any description have been seen in positions near a horizontal plane. No trace of anything like an approach to a laccolitic structure has been observed in any part of this field.

This enumeration does not include the large masses of diorite in the valley of the Annisquam Fiord nor the great masses of granite porphyry which lie in the same region and on the east shore of Cape Ann.

The range in diameter of the dikes is from a width of forty feet to very narrow intrusions with a width of half an inch, fine stringers often being not more than one-tenth of an inch in diameter at twenty feet from the main mass.

Owing to the conditions of exposure it has not proved possible to trace the horizontal extension of these injections. It is worthy of note, however, that in no case has it proved possible to find both ends of any injection, and in less than half a dozen cases has either extremity been seen. Considering the large number of dikes examined and the fact that many of them have been traced for hundreds of feet, it becomes clear that the longitudinal extension of these fissures is generally great. In the case of one dike, the great porphyritic intrusion of Pigeon Cove, there can be no question that it ex-

tends from a position one-fourth of a mile southwest of Straitsmouth Point, beneath Sandy Bay, to Pigeon Cove, and thence across the island to near Folly Cove. It is true that a portion of this extent is hidden by the sea, but such is the similarity in the physical charac-

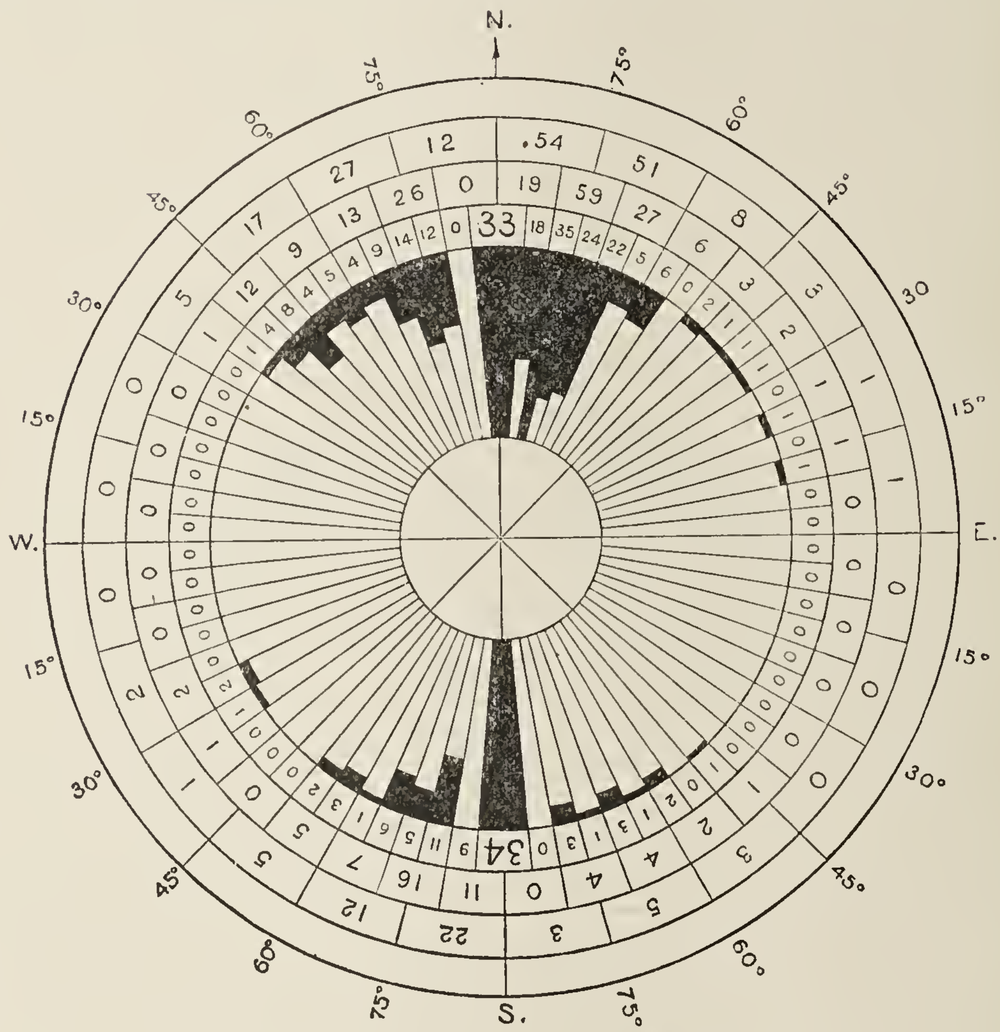
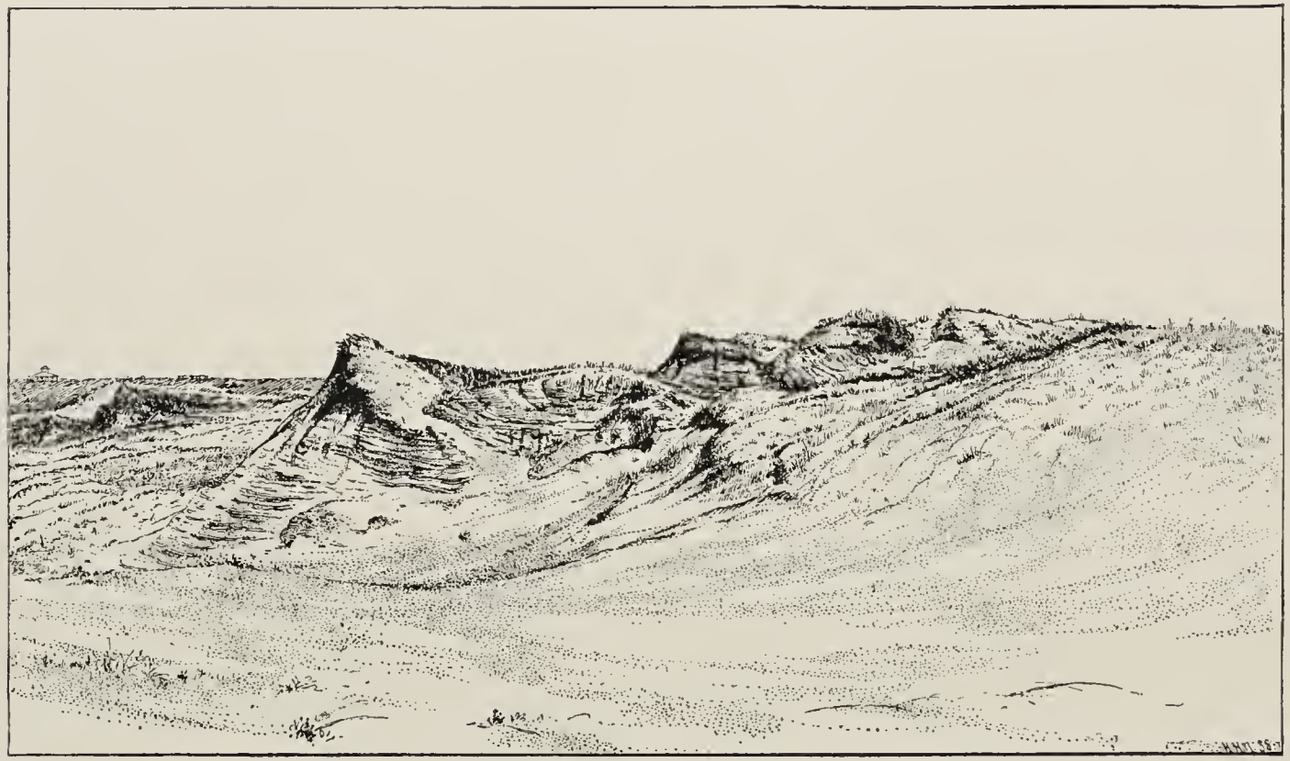


FIG. 46. Tabulation of dips of dikes on the island of Cape Ann.

ter, general strike, and other features of the injection, that the identity of the dike throughout its length can hardly be doubted. The distance between these two points is about three miles.

These dikes in great part are characterized by clean walls, and as a whole they are not greatly cross-faulted, that is, the sides of the fissures are on the whole parallel, and there are few offsets. (See Pls. LXIV, LXV.) A certain group of quartz-porphyry dikes hereafter to be considered in detail have generally very irregular walls. In this case, however, there is no distinct indication of melting of the bounding walls, so that we can not perhaps regard the dikes as volcanic pipes, but must rather attribute the irregularity of their boundaries to some peculiar violence in the outbreak which produced them, or it may be that these ruptures were formed before the development of the joint planes. This latter conjecture is favored by the fact that these quartz porphyries are clearly the



SAND DUNES OF COFFIN'S BEACH.

oldest dikes in this section. Moreover, they are in a given field more faulted than the other dike systems, and therefore are shown to be of earlier age.

The faulting which has affected the district is principally indicated in the earliest set of dikes, viz., the quartz porphyries just mentioned. It is very slightly manifested in the case of the other fissures, and is indicated only at the points of intersection of different sets of dikes. It thus appears that the disruptive forces which produced the faulting did not, to any considerable extent, operate in this field after the work of intrusion was completed.

AREA OCCUPIED BY DIKES.

At this point we may notice an interesting theoretical consideration dependent upon the number of dikes in this region and the area which they occupy. Basing a computation, first, on a careful eye-estimate of the dike surfaces at different points, and, secondly, on an estimate of the number and diameter of the dikes, it appears pretty certain that on the surface of Cape Ann 5 to 10 per cent. of the superficial area is occupied by such materials. In other words, the horizontal extension of the granites has been increased by somewhere between one-tenth and one-twentieth of the original surface. Besides this increase, due to the injection of materials derived from below, the rocks have received a certain small though incomputable accession from vein materials, principally composed of quartz. In other districts this vein element is an important feature in the extension of the area. On Cape Ann it is so small that we may neglect it.

No particular order in the distribution of these veins has been observed. They are eminently abundant on Eastern Point, near Annisquam, and in the quarries about Rockport; they are rare elsewhere. They seldom exceed two or three inches in diameter and are generally of no considerable length. They do not appear to be connected with the faults, and are, therefore, probably in their nature secretions from the granitic mass formed during the cooling process.

I have elsewhere called attention to the fact that the injection of dike and vein stones would lead perhaps in part at least to movements of the strata which have resulted in the formation of anticlinal axes. It is interesting in this connection to note that a considerable extension of these basement deposits of the Gloucester anticline has taken place.

JOINT PLANES OF CAPE ANN DISTRICT.

The joint planes of the Cape Ann District as will be seen from the appended tables have been subjected to a careful study. I am not aware that in any preceding memoir involving a similarly extensive district the observations have been presented in an equally elaborate

manner. The observations on these joint planes were made by a compass with a needle having a length of four inches, the circle graduated to degrees with a vernier attachment. In the course of the work, it quickly became evident that it was not possible on account of the decay of the rocks to observe joint phenomena in natural exposures with sufficient accuracy to obtain valuable results. The tabulated work, therefore, has been limited to quarries. It hap-

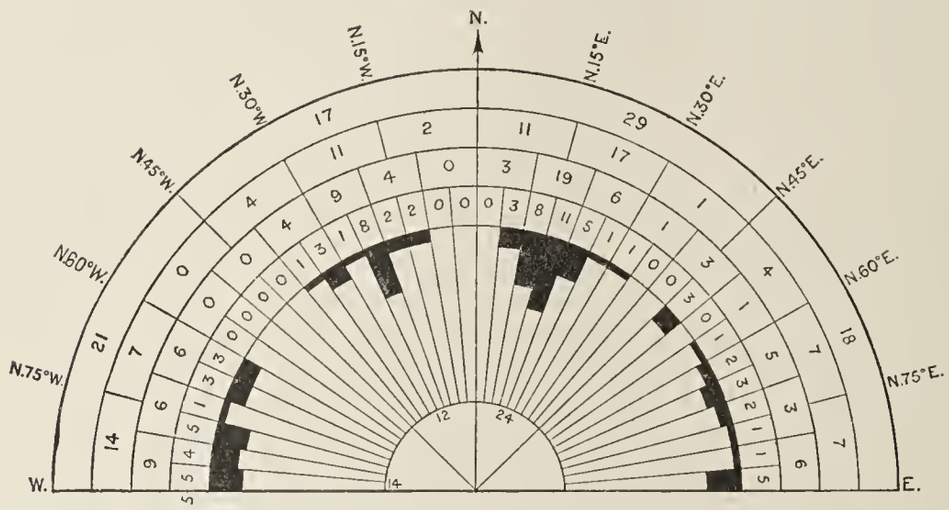


FIG. 47. Tabulation of joint planes in Bay View quarries.

pens, however, that these artificial openings are so far distributed over the area of the island that they fairly represent the joint systems of the whole district. (See Figs. 48 and 49.) Inasmuch, however, as the general phenomena of joints along the coast are of great importance in determining the action of erosive forces, the detailed study of

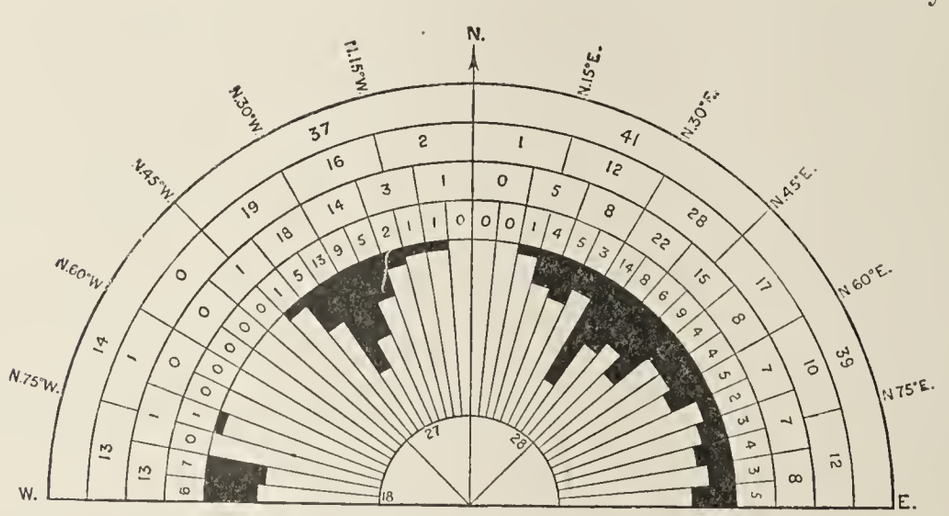
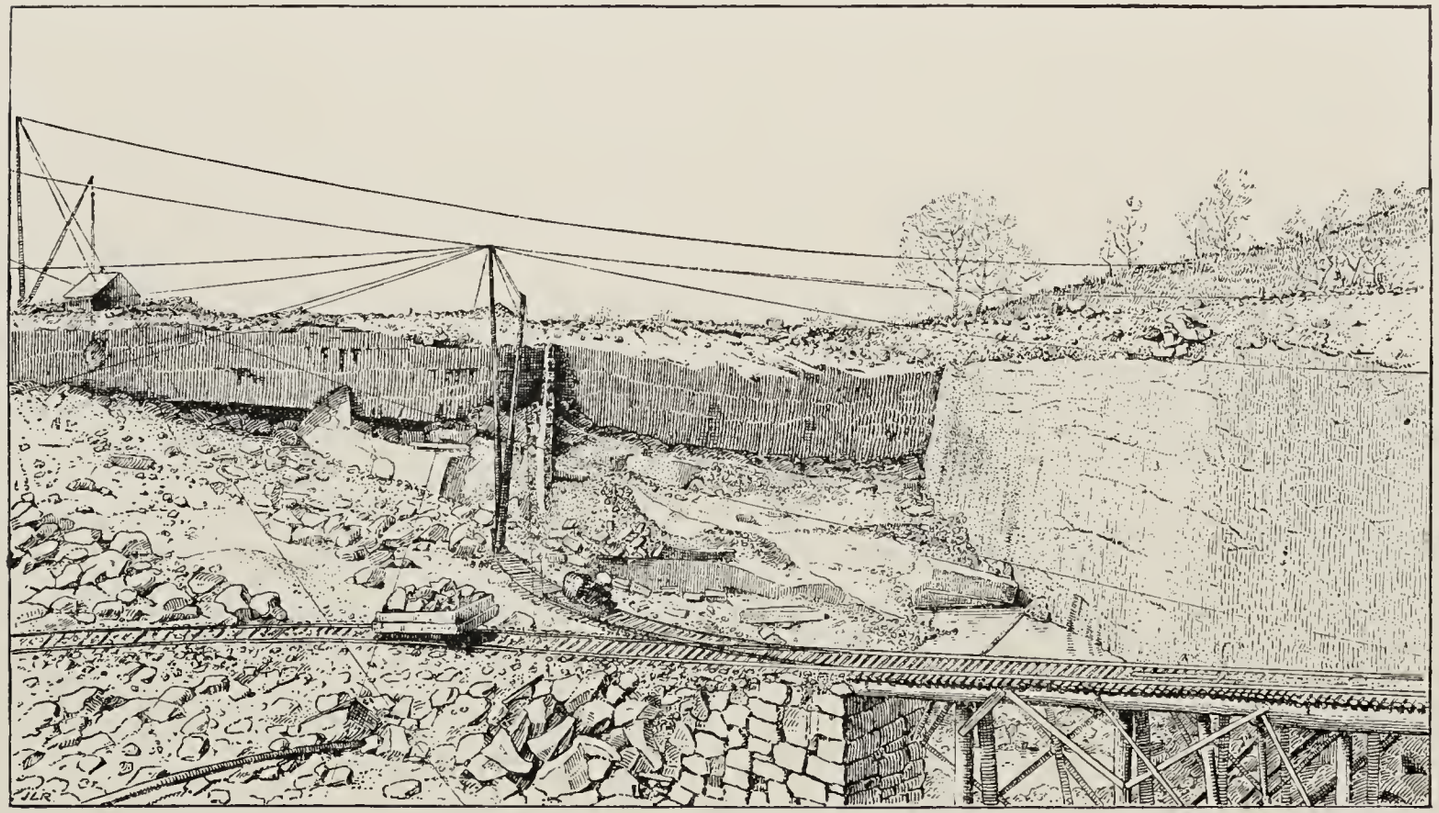


FIG. 48. Diagrammatic illustration of distribution of joint planes in Lanesville quarries.

joint planes will be preceded by a general statement of their character on different parts of the coast, beginning as in the case of dikes with Eastern Point. Eastern Point as far as Brace's Cove exhibits much jointing, the principal fractures having an axis of N. 48° to N.



PIGEON HILL QUARRY, UPPER PIT, SHOWING EXTREME DEVELOPMENT OF HORIZONTAL JOINTING.

53° E., dipping nearly vertically, a distance of eight feet apart, varying from one inch to 20 feet, and averaging three or four feet. There are other joints in the same region which can not clearly be referred to any system. Owing to the high angles of the principal joints, the weather and ice have not much affected the rocks in this portion of the section, and as a consequence it is one of the boldest portions of the shore of the island. In the vicinity of Brace's Cove the joint planes are close together, averaging less than a foot apart, and inclining in various directions, so that the rock splits in small fragments of little more than one-fiftieth of a cubic foot. It is probably to this morcellated character of the rock given by the joints that we owe the great erosion of the granites which has formed the low land in which lie Brace's Cove, Niles's Pond and the other depressions of this vicinity.

From Brace's Cove to Bass Rocks the manifest joint systems are fewer in number and the places farther apart. With this diminution in jointing, the shore again assumes a bold character. At Bass Rocks the joint structure is very imperfectly developed (Pl. LIX), the rocks being here perhas more massive than at any other point on the periphery of the island, although the dike injections are more numerous here than elsewhere. From Bass Rocks to Cape Hedge the joints are again more numerous, and to this greater development may perhaps be due the recession of the shore on this part of the island. At certain points the jointing in the measure of its development approaches the conditions shown at Brace's Cove. From Cape Hedge to Straitsmouth Point, there are but two distinct vertical systems of joints which are evident, viz, those running N. 48° W. and those running N. 32° E., together with a horizontal set, the three serving to detach numerous very massive fragments. At several points on this portion of the coast are small patches of granite which are almost as much jointed as the large field of such material at Brace's Cove. Wherever these patches occur the effect of marine erosion is at once evident. The coast line is beaten back until in process of retreat it obtains a certain protection from the assault of waves from detritus which lodges in the re-entrant angle. Going north from Eastern Point this is the first portion of the shore on which the horizontal jointing distinctly appears.

On the south shore of Sandy Bay, between Straitsmouth Point and the village, the vertical jointing runs N. 3° W. and N. 52° E. At this point the distinct horizontal joint planes become less marked and are replaced by a number of divergent planes. From Sandy Bay along the shore to Folly Cove, we have the conditions of jointing which are shown in detail in the Pigeon Cove quarries. (See Pls. LXVI, LXVII, LXVIII, LXIX, LXX, LXXI.) The planes strike N. 78° W. with a dip to the NE. of 55°. Another set of nearly horizontal shelving somewhat irregular joint planes strikes in a general

way east and west, dipping to the south at an angle of 10° or 12°. Yet another set strikes N. 43° E. with a vertical dip. These three joints lead to the formation of rhomboidal fragments which are frequently as much as 4 feet wide, 12 feet long and varying from 1 to 4 feet in thickness. The size of these fragments shows that the joint planes are far apart. The attitude of the planes towards each other and their

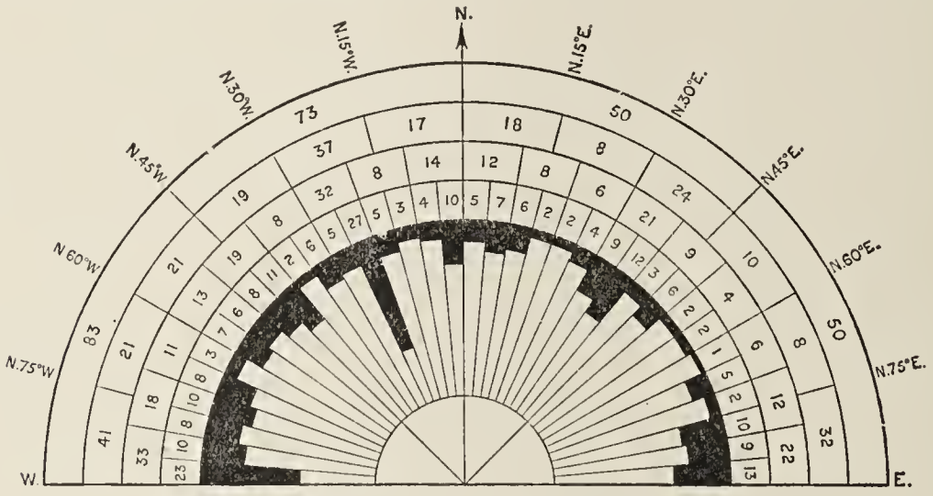


Fig. 49. Tabulation of joints in Rockport quarries.

position in relation to marine erosion has doubtless served to protect this part of the island from glacial and other wearing, and has thus led to the preservation of the great salient which terminates in Halibut Point. So, too, the generally level character of this area and the gradual slope with which it meets the sea may be accounted for by

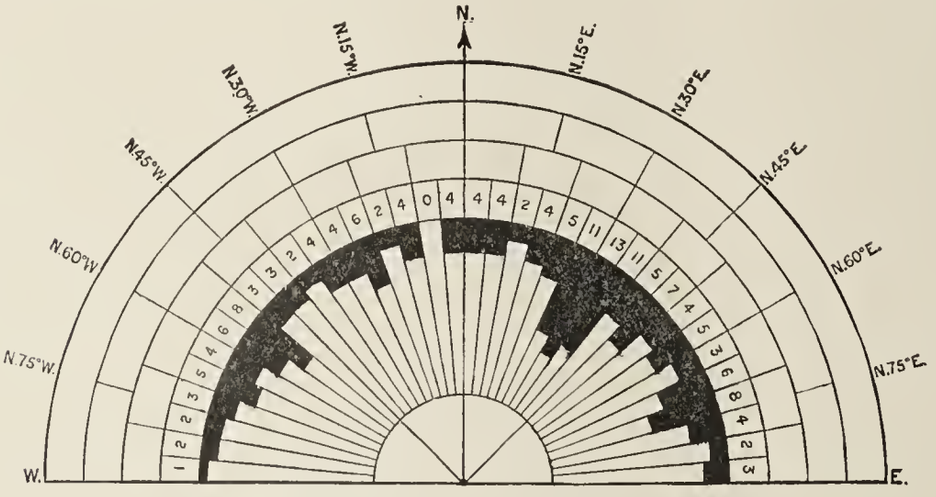


Fig. 50. Tabulation of joint planes in Pigeon Cove quarries.

the attitude of the joint systems. The joints of this section, particularly those which strike N. 43° E., are remarkable for the continuity of the individual planes. In some cases they may be observed extending on the shore line for the distance of 300 feet or more.

BASALTIC JOINTING IN DIKE AT STONE BRIDGE ONE-QUARTER OF A MILE EAST OF GLOUCESTER.

The rock is less cut by joint planes and therefore more massive in the region about Andrews Point. At Halibut Point, the strong northeast waves have disrupted a large quantity of material which serves in a measure to protect the shore from the further assault of the waves. The vigor of the wave action is shown by the size of the fragments thrown up far beyond the ordinary range of the sea. Between Halibut Point and Folly Cove is a section of rock which has been subjected to interstitial decay and exposes the joint planes imperfectly. The depression of Folly Cove and the trough which extends southward for a mile or more from its head is perhaps caused by a lack of resistance in the material. Folly Point is characterized by a considerable immunity from jointing. These joints are at this point so irregular that it does not seem possible to reduce them to definite sets.

A moderate immunity from joints characterizes the whole shore from Folly Cove to Annisquam, and here also it has not proved possible to reduce the joint planes to a definite order.

The shores of Annisquam Reach exhibit a system of very closely juxtaposed joints which so divide the rock that it normally breaks up into fragments not exceeding about ten cubic inches in contents. It is perhaps to the ample jointing of this section that we owe the deep and continuous depression in which lies this system of fiord of Annisquam River. (See diagrams of jointing in quarries, Figs. 50, 51, 52, and Pls. LXXII, LXXIII, LXXIV.)

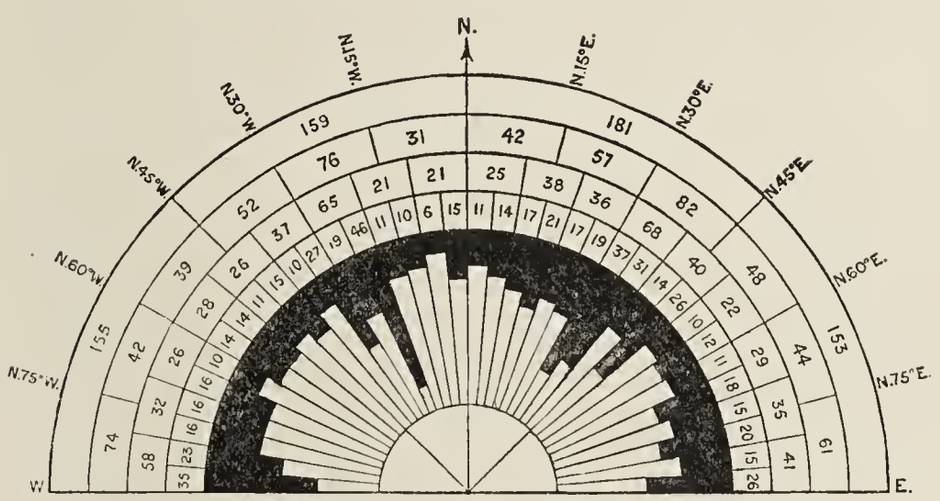


FIG. 51. General tabulation of joint planes.

The foregoing survey of the shore from the point of view of joint planes, makes it tolerably evident that there is some relation between the salients and re-entrants of the coast line and the jointed character of the rocks. A study of the field would show the student that this is the case more effectively than it is indicated to him by the necessarily cursory account which we have given him. In fact,

the measure of resistance both to marine and glacial action, the two modes of erosive energy which have in the main shaped this region, is in good part determined by the attitude of the joint planes. The preceding pages afford a basis for this general description as far as the sea shore and wave action are concerned. Evidence of a similar sort may readily be found to show the influence of the joint planes on glacial wear. Thus whenever the granitic rocks form sharp projections in the interior district, we always find these salients to be composed of little jointed material, while in the depressions a variety of evidence freely leads to the inference that they are occupied by rocks more closely intersected by these rupture planes.

Turning now to the conditions in the several quarries, we note the following facts concerning joints in different parts of the field which have been bared by quarrying work. Fig. 50 exhibits the attitude of the joint planes in the Rockport system. It will be seen by the diagram that the joints having their planes in the northwest quadrant amount to 156, while those in the northeast quadrant amount to but 100; those in the north-northwest octant to 73, while those in the northwest-by-west octant amount to 83. Thus, as in the case of the dikes, though in a less degree, there is in this particular part of the field an accumulation of joints in the northwest quadrant.

In the Pigeon Cove quarries (see Fig. 51) the conditions are reversed. There are 53 joint planes in the northwest quadrant and 101 in the northeast quadrant. In the Lanesville quarries the conditions are like those at Pigeon Cove, with a proportionately greater number in the northeast quadrant, the numbers being 51 in the northwest quadrant and 80 in the northeast quadrant. In the Bay View quarries, there is very little difference between the number of joints in the two quarries, there being 38 in that of the northwest and 47 in the northeast quadrant.

Thus it appears as the result of sufficiently numerous observations of the joint planes and their associated dikes that while the dikes distinctly follow joint planes there does not appear to be any such relation between them as would enable us to say that the number of dikes was in any measure determined by the number of incipient fissures afforded by the joints, or, in other words, the conditions which guided the direction of the dikes were probably due to some feature or condition not inherent in the joints themselves.

ROCKPORT GRANITE COMPANY'S QUARRY, SHOWING ABSENCE OF VERTICAL JOINTS AND CHANGE IN CHARACTER OF PLANES IN THE DEEPER PARTS OF THE SECTION.

LIST OF DIKES OF CAPE ANN.

[The numbers in the following list refer to corresponding numbers upon the map of the bed rocks of Cape Ann. The identification of the dike rocks has been mainly from hand specimens and necessarily no attempt has been made to classify them upon strictly petrographical grounds.]

No. on map.	Strike.	Dip.	Width.	Name.	General remarks.
1	N. 17° E.	85° W.	2½ feet	Diabase	An irregular dike.
2	N. 77° E.	75° N.	2 feet	Porphyritic diabase	Somewhat faulted.
3	N. 2° E.	70° SE.	10 feet	Quartz porphyry	
4	N. 72° E.		2½ feet	Porphyritic diabase	
5	N. 12° E.	60° W.	12 feet	Diabase	
6	N. 77° E.	85° N.	3 feet		Worn into a deep chasm for considerable distance above high tide.
7	N. 77° E.	60° N.	1½ feet	Diabase	
8	N. 12° E.	75° W.	7 feet	Quartz porphyry	
9	N. 17° E.	90°	2½ feet	Porphyritic diabase	An irregular dike.
10	N. 3° W.	75° N.	8 feet	Quartz porphyry	
11	N. 13° W. to N. 22° E.	75° W.	11 feet	Diabase	Crystals of feldspar 6 inches long.
12	N. 27° E. to N. 13° W.			do	A chasm.
13	N. 58° to 81° W.	90°	3 to 6 feet.		
14	N. 12° E.			Feldspar porphyry	
15	N. 83° W. to N. 57° E.	90°	3½ feet	do	A very irregular dike.
16	N. 21° to 42° E.	80° N.	3 feet	Diabase	
17	N. 62° E.	80° N.	4 feet	Porphyritic diabase	Very irregular. Cuts 16.
18	N. 53° W.		8 inches	Diabase	
19	N. 47° E.	90°	3½ feet	do	
20	N. 67° E.		2 feet	do	
21	N. 82° E.	90°	2 feet		
22	N. 77° E.	75° N.	3 feet	Diabase	
23	N. 62° E.	50° S.	½ inch to 4 feet.	Feldspar porphyry	Very irregular and ragged.
24	N. 42° E.	60° N.	3½ feet	Diabase	
25	N. 47° E.		8 inches		
26	N. 32° E.	55° N.	3 feet		
27	N. 22° to 42° E.	90°	2½ feet	Diabase	
28	N. 57° E.	75° N.	3½ feet		
29	N. 13° W.	80° N.	7 feet	Diabase	A chasm.
30	N. 87° E.	80° N.	15 to 18 feet	do	
31	N. 43° W.	80° SW.	6 feet		
32	N. 28° W.	60° E.	2 feet	Diabase	
33	N. 33° W.	90°	1½ feet		
34	N. 78° W.	60° W.	2½ feet		
35	N. 83° W.	70° N.	18 feet	Diabase	Irregular.
36	N. 43° W.	90°	3½ feet	do	
37	N. 27° E.	60° SE.	2 feet		
38	N. 25° W.	90°	1 foot.	Diabase	
39	N. 38° W.		6 feet		
40	N. 33° W.		2 feet		
41	N. 38° W.	70° SW.	2 feet	Diabase	
42	N. 63° W.	85° SW.	3 feet	Porphyritic diabase	Very irregular.
43	N. 27° E.	60° NW.	4 feet	do	
44	N. 33° W.	80° SW.	4 feet		

List of dikes of Cape Ann—Continued.

No. on map.	Strike.	Dip.	Width.	Name.	General Remarks.
45	N. 13° W	80° SW	2 feet	Diabase	
46	N. 33° W to N. 37° E.	55° SW	1 foot		Very irregular.
47	N. 42° E.	70° NW	6 inches		
48	N. 13° W	60° NE	3 feet		Rather irregular.
49	N. 77° E.	70° S.	3 feet		
50	N. 43° W		6 to 8 inches		Very irregular.
51	N. 53° W	90°	2½ feet		
52	N. 37° E.	70° SW	5 feet	Feldspar porphyry	
53	N. 49° W	90°	1½ feet	do	
54	N. 37° E.	70° NW	4 feet	Diabase	
55	N. 58° W	90°	22 feet	Feldspar porphyry	Cut by 57 and probably by 56.
56	N. 47° E.	50° NW	10 feet+		
57	N. 47° E.	75° N	7 feet	Diabase	
58	N. 58° W	70 to 80° NE	20 feet		
59	N. 62° E.	75° W.	3 feet	Diabase	
60	N. 52° E.	80° N	2½ feet	do	
61	N. 49° E.	90°	4 feet	do	
62	N. 77° E.	75° N	4 feet	do	
63	N. 47° E.	75° N	3 feet+	do	
64	N. 27° E.			do	A chasm with the dike matter washed out.
65	N. 58° W	90°	3 to 4 feet.	do	Very irregular.
66	N. 1° W	35° W.	4 inches	do	Disappears.
67	N. 52° E.	65 to 70° N.	2½ inches	do	
68	N. 41° W	90°	1 foot	do	
69	N. 38° W	90°	4½ feet	do	
70	N. 77° E.	75°	6½ feet	Feldspar porphyry	
71	N. 13° W	90°	4 to 5 feet.	Diabase	
72	N. 33° W	90°	9 feet	do	
73	N. 7° E.	90°		do	73 cuts 70.
74	N. 53° W	83° S.	1½ inches	do	Disappears.
75	N. 43° W	75° S.	1½ to 2½ inches.	do	
76	N. 53° W	80° S	3½ feet	do	
77	N. 59° W	90°	3¼ feet	do	
78	N. 33° W	80° NE.	3½ feet	do	78 branches forming 78ª.
78ª	N. 18° W	75° E.	3½ feet	do	
79	N. 18° to 33° W.	90°	4 feet+		Dike matter eroded away.
80	N. 63° W	90°	7 feet	Diabase	
81	N. 33° W	75° W.		do	
82	N. 61° W	90°	1 foot	do	
83	N. 35° W	80° E.	6 feet		
84	N. 30° E.	70° N (?)	10 feet (?)	Diabase (?)	
85	N. 51° W		6 feet+	Diabase	
86	N. 49° E.	70° S.	5 inches to 1 foot.	do	
87	N. 43° W	80° E.	4 feet		
88	N. 49° W	80°+		Diabase	
89	N. 57° E.	75° S.	2 to 3 feet.	do	
90	N. 23° W		6 feet	do	
91	N. 47° E.		8 feet	do	
92	N. 27° E.	45° N	3½ feet	Feldspar porphyry	
93	N. 23° W	80 to 85° E.	3 feet	Diabase	

DORMAN'S QUARRY, ON SIDE OF MAIN ROAD FROM ROCKPORT TO PIGEON COVE, SHOWING TWO PRINCIPAL SETS OF JOINTS.

List of dikes of Cape Ann—Continued.

No. on map.	Strike.	Dip.	Width.	Name.	General Remarks
94	N. 63° W	90°	21 feet	Diabase	
95	N. 87° E.	90°	1½ feet	do	
96	N. 47° E.	80° N	1½ feet	do	
97	N. 6° E.	80° SE	1½ feet		
98	N. 43° W		5 feet		
99	N. 53° W	80° NE			Irregular.
100	N. 47° E.	75° N	½ inch		
100[a]	N. 17° E.	75° NW	1 inch		
100[b]	N. 37° E.	75° N	2½ inches		
101	N. 48° W		1 foot		
102	N. 37° E.	75° N	1½ feet	Diabase	
103	N. 13° W	70° E	1 foot		
104	N. 58° W.		15 feet +	Holocrystalline diabase.	
105	N. 43° W. to N. 57° E.	70° S.	6 inches to 1½ feet.	Diabase	Very irregular.
106	N. 13° W	70° E.	1½ feet	do	
107	N. 37° E.	90°	3 feet	do	
108	N. 9° W	70° E.	12 feet	do	
109	N. 33° W	82° W.	3 feet	do	Probably an offshoot of 108.
110	N. 38° W	90°	3 feet	do	
111	N. 23° W	90°	5 to 6 inches	do	
112	N. 23° W	75° E.	4 inches		
113	N. 33° W		3 feet	Feldspar porphyry	Forked dike.
113[a]	N. 58° W	50° NE.	2½ feet	do	do.
113[b]	N. 43° W	65 to 85° NE	2 feet	do	do.
114	N. 35° W	80° E.	2½ feet		
115	N. 23° W	75° E.	9 feet		
116	N. 33° W	15° E.	1 foot	Quartz porphyry	Very irregular.
117	N. 23° W	85° E.	2½ feet	Diabase	
118	N. 27° E.	50° NW.	8 inches	do	do.
119	N. 17° E.	45° W.	1½ feet	do	Forked dike.
119[a]	N. 17° E.	45° W.	1 foot	do	do.
119[b]	N. 32° E.	45° W.	1 foot	do	do.
120	N. 57° E.	50° NW.	2 feet	do	Cuts 121.
121	N. 33° W	90°	10 feet	do	Extremely irregular and faulted.
121[a]	N. 43° W	90°	10 feet	do	do.
121[b]	N. 13° W.	70° E	2 feet	do	do.
121[c]	N. 43° W	90°	2 feet	do	do.
122	N. 38° W.	60° E.	1 foot	do	
123	N. 28° W	80 to 85° NE	6½ feet	do	Forked dike.
123[a]	N. 35° W	85° NE.	6½ feet	do	do.
123[b]	N. 43° W	80° NE.	2 feet	do	Offshoot of 123.
124	N. 33° W	90°	9 feet	Porphyritic diabase	
125	N. 43° W	90°	1 foot		
126	N. 67° E.	70° S.	2 feet	Diabase	
126[a]	N. 77° E.	65° S.	6 inches	do	
126[b]	N. 73° W	70° S.	1 foot	do	
126[c]	N. 12° E	60° S	1 foot	do	
127	N. 37° E.	60° N	10 feet	Quartz porphyry	
128				do	Very ragged and irregular.
129	N. 77° E.		15 feet	do	Irregular.
130	N. 18° W	80° E.	10 feet	Diabase	
131	N. 33° W	80° SE.	2 feet	do	

List of dikes of Cape Ann—Continued.

No. on map.	Strike.	Dip.	Width.	Name.	General remarks.
132	N. 53° to 63° W.	.....	2 feet.....	Diabase	
133	N. 47° E.....	40° N	8 inches...	.....do	
134	N. 27° to 57° E.	50° N	2 feet.....	.....do	
135	N. 47° E.....	65° N	50 to 60 feet	Quartz porphyry	Very irregular and ragged.
136	N. 83° W	45° N	3½ feet....	Diabase	
137	.....	.....	....	Quartz porphyry	Ragged and irregular.
138	N. 21° W	75° NE....	2 feet.....	Diabase	Irregular.
139	N. 3° W	80° NW ...	2 feet.....	.... .do	
140	N. 13° W	76° NW ...	3 feet.....	.. . .do	
141	N. 5° E. to 13° W.	.. ..	8 feet.....	.. . .do	
142	N. 32° E.....	.....	10 feet+..	....	
143	N. 18° W	90°.....	1 foot.....	.....	
144	N. 32° E..	45° NW ...	7 feet.....	Diabase	
145	N. 32° to 67° E.	55° NW ...	6 feet.....	....	
146	N. 67° E.....	80° N	.....	.....	
147	N. 53° W.	....	2½ feet....	Spherulitie quartz porphyry.	
148	N. 13° W	.....	2 feet.....	....	
149	N. 3° W	90°.....	2 feet.....	.....	
150	N. 83° W	80° N	5 feet.....	Diabase	
151	N. 48° W	85° S	9 feet.....	.....do	
152	N. 47° W	85° S.....	9 feet....	.....do	
153	N. 52° E.	....	2 feet....	.....do	Irregular.
154	N. 47° E.....	55° N	.....	.....do	Cut by 157.
155	N. 32° E.	60° N	6 feet.....	. ...do	Irregular.
156	N. 33° W	90°.....	2¼ feet....	.....do	
156[a]	N. 33° W	65° E.....	1 foot.....	.....do	
157	N. 47° E.....	90°...	2 feet.....	.....do	
158	N. 13° W	90°..... ..	1½ feet....	Feldspar porphyry	
159	N. 23° W	80° NE....	8 feet.....	..... do	Irregular.
160	N. 47° E.....	60° NW ...	20 feet+..	....	
161	N. 23° W	80° NE....	7 feet.. ..	....	
162	N. 13° W	90°.....	2 feet.....	Nelaphyric diabase ...	
163	N. 31° W	.....	10 feet+..	Diabase	
164	N. 30° W	80° NE....	3½ feet....	.....do	
165	N. 7° E.....	50° W.....	4½ feet....	.....do	Irregular.
166	N. 13° W	90°..	3 feet.....	.....do	
167	N. 41° W	75° E.....	12½ feet...	.....do	
168	N. 37° W	68° SW ...	1 foot.....	.....do	
169	N. 25° W	75° NE....	4 feet.....	....	
170	N. 13° W	35° NE....	1½ to 2½ feet	Diabase	
171	N. 7° E.....	50° NE....	1 foot.....	.....do	
172	N. 9° W	80° NE....	18 feet....	.....do	
173	N. 23° W	80° NE....	3 to 3½ feet.	Porphyritic diabase	
174	N. 32° E.....	55° N	3 feet.....	Diabase	
175	N. 21° W	80° NE...	18 feet....	Porphyritic diabase	Same as 172.
176	N. 37° W	30° S.....	1 foot.....	Quartz porphyry	
177	N. 77° E.....	75° N	18 feet....	Diabase	
178	N. 73° E.....	75° N	21 feet....	.....do	
179	N. 83° W	70° N	1 foot 5 inches.	.....do	
180	N. 78° W	80° N	2¼ feet....	.....do	
181	N. 87° E.....	80° N	3 inches...	....do	
182	N. 73° W	65° W.....	3½ feet....	Feldspar porphyry	

ROCKPORT GRANITE COMPANY'S QUARRY NORTHERN END OF LOWER PIT, SHOWING PROGRESSIVE INFREQUENCY OF JOINTS AT DEPTHS BELOW THE SURFACE.

List of dikes of Cape Ann—Continued.

No. on map.	Strike.	Dip.	Width.	Name.	General remarks.
183	N. 41° W	70° NE.	5 feet	Feldspar porphyry	Irregular.
183[a]	N. 87° E.	80° NE.	3 feet	do	
184	N. 43° W.	85° NE.	1 foot 5 inches.	do	Offshoot of 183.
184[a]	N. 45° W		4 feet	do	
185	N. 27° E.	65° W.	3½ feet	Diabase	
185[a]	N. 77° E.	80° N	16 feet	do	
186	N. 7° E	70° N	25 to 35 feet		
187	N. 2° E.	70 to 80° W.	3 feet	Altered porphyritic diabase.	Chasm.
188	N. 77° E.		3 feet	Diabase	
189	N. 53° W	75° S.	2 feet		Irregular.
190	N. 43° W	86° NE.			
191	N. 43° W	80° E.	8 feet	Diabase	
192	N. 53° W				
193	N. 27° E.	55° N	4 feet	Diabase	Chasm.
194	N. 53° W	90°	5 feet	do	
195	N. 38° W	85° E.	10 feet	do	
196	N. 42° E.		30 feet	Altered porphyritic diabase.	Same as 187 (?) Irregular.
197	N. 83° W		20 feet	Diabase	
198	N. 32° E.	70° N	14 feet	do	
199	N. 47° E.		½ inch to 1½ feet.		
200	N. 53° W		3 feet	Diabase	Irregular.
201	N. 47° E.			Altered diabase	
202	N. 57° E.	70° N	10 feet	Diabase	
203	N. 77° E.	70° N	5½ feet	do	
204	N. 37° E.	45° N	2½ feet	do	Disappears.
205	N. 82° E.	80° N	22 feet	do	
206	N. 58° W	75° W.	2 feet	do	
207	N. 58° W	90°	2½ feet		
208	N. 78° W	75° N	2½ feet	Feldspar porphyry	
208[a]	N. 28° W	65° NE.	6 feet	do	
208[b]	N. 28° W	80° NE.	12 feet	do	
209	N. 47° W	75° NE	2 feet	Diabase	
210	N. 29° W.	75° NE.	4 feet	do	
210[a]	N. 38° W	80° NE.	3 feet	do	
210[b]	N. 33° W	75° NE.	3 feet	do	
211	N. 43° W	80° NE.	3 feet		
211[a]	N. 43° W	80° NE.	1½ feet		
212	N. 33° W.	80° NE.	18 to 20 feet	Very augitic diabase	
213	N. 38° W		3 to 4 feet		
214	N. 37° E.			Feldspar porphyry	Very irregular.
215	N. 23° W.	80 to 85° E.	15 feet	Diabase	
216	N. 48° W		3 feet	do	
217	N. 77° E.	70° N	4 feet	do	
218	N. 28° W	90°	9 feet	do	
219	N. 77° E.	50° N	1½ feet	Diorite (?)	
220	N. 33° W	85° E.	1 foot		
221	N. 13° W		1½ feet	Diabase	
222	N. 77° E.				
223	N. 58° W	80 to 85° NE	3 feet		
224	N. 38° W	85° NE.	1½ feet		

List of dikes of Cape Ann—Continued.

No. on map.	Strike.	Dip.	Width.	Name.	General remarks.
225	N. 33° W		2 feet		
226	N. 50° W	90°	9 feet		
227	N. 43° W	50° NE.	10 feet	Quartz porphyry	
228	N. 33° W	90°	3 feet	Diabase	A bow-shaped dike.
228[a]	N. 83° E.	90°	3 feet	do	do.
229	N. 33° W	90°	3 feet	do	
230	N. 37° W	80° W.	30 feet		
231	N. 13° W		5 to 10 feet.	Diabase	
232	N. 39° W	80° NE.	3 feet	do	
233	N. 31° W	90°	2½ feet	Feldspar porphyry	
234	N. 13° W			Diabase	Very irregular.
235	N. 31° W	80° NE.	9 feet	Feldspar porphyry	
236	N. 23° W	85° NE.	1½ feet	Diabase	
237	N. 37° E.			Diorite porphyrite	
238	N. 33° W		1½ feet	Diabase	
239	N. 13° W	90°	3 feet		
240	N. 13° W	90°	3 feet		Cut by 241 and 241[a].
241	N. 73° W	75° N	9 feet	Diabase	Irregular and very much branched.
241[a]	N. 88° W	75° N	5 feet	do	do.
241[b]	N. 58° W		¾ inch	do	do.
241[c]	N. 58° W		5 inches	do	do.
241[d]	N. 58° W		½ to 5 inches	do	do.
241[e]	N. 13° W		8 inches	do	
241[f]	N. 13° W		5 inches	do	
242	N. 33° W	70° NE.	12 feet	do	
243	N. 33° W	90°	2½ feet	Porphyritic diabase	
244	N. 37° W	70° NE.	4 to 5 inches	Diabase	Irregular.
245	N. 33° W	80° NE.	1¾ feet	Quartz porphyry	
246	N. 28° W	80° NE.	21 feet	Diabase (?)	
247	N. 33° W	80° SW.	2½ feet		
247[a]	N. 33° W	80° SW.	2 feet		
247[b]	N. 43° to 63° W.		2 feet		
247[c]	N. 33° to 68° W.				Joining 247[d].
247[d]	N. 33° W	80° SW.	3 feet		
248	N. 43° W		½ to 2 feet.	Diabase	
249	N. 38° W	90°	3 feet	do	
250	N. 43° W	75 to 80° SW.	4 feet		
251	N. 48° W	80° S	3 inches		
252	N. 37° W	80° SW.	3 to 4 feet.	Diabase	
252[a]	N. 23° W	85° SW.	15 inches		
253	N. 33° W	90°	1 foot		
254	N. 48° W	80° SW.	3 feet 3 inches.	Diabase	
255	N. 33° W	90°	10 feet	do	
256	N. 53° W	88° S.	4 feet	do (?)	
257	N. 13° W	25° E.	3½ feet	do	
258	N. 35° W	75° E.	15 feet +	do	
259	N. 37° W	75° NE.	3½ feet	do	
260	N. 45° W	90°	3 feet		
261	N. 25° W	70° NE.	3 feet		
262	N. 38° W		15 feet +		
263	N. 29° W		2 feet		
264	N. 33° W		10 feet +	Diabase	

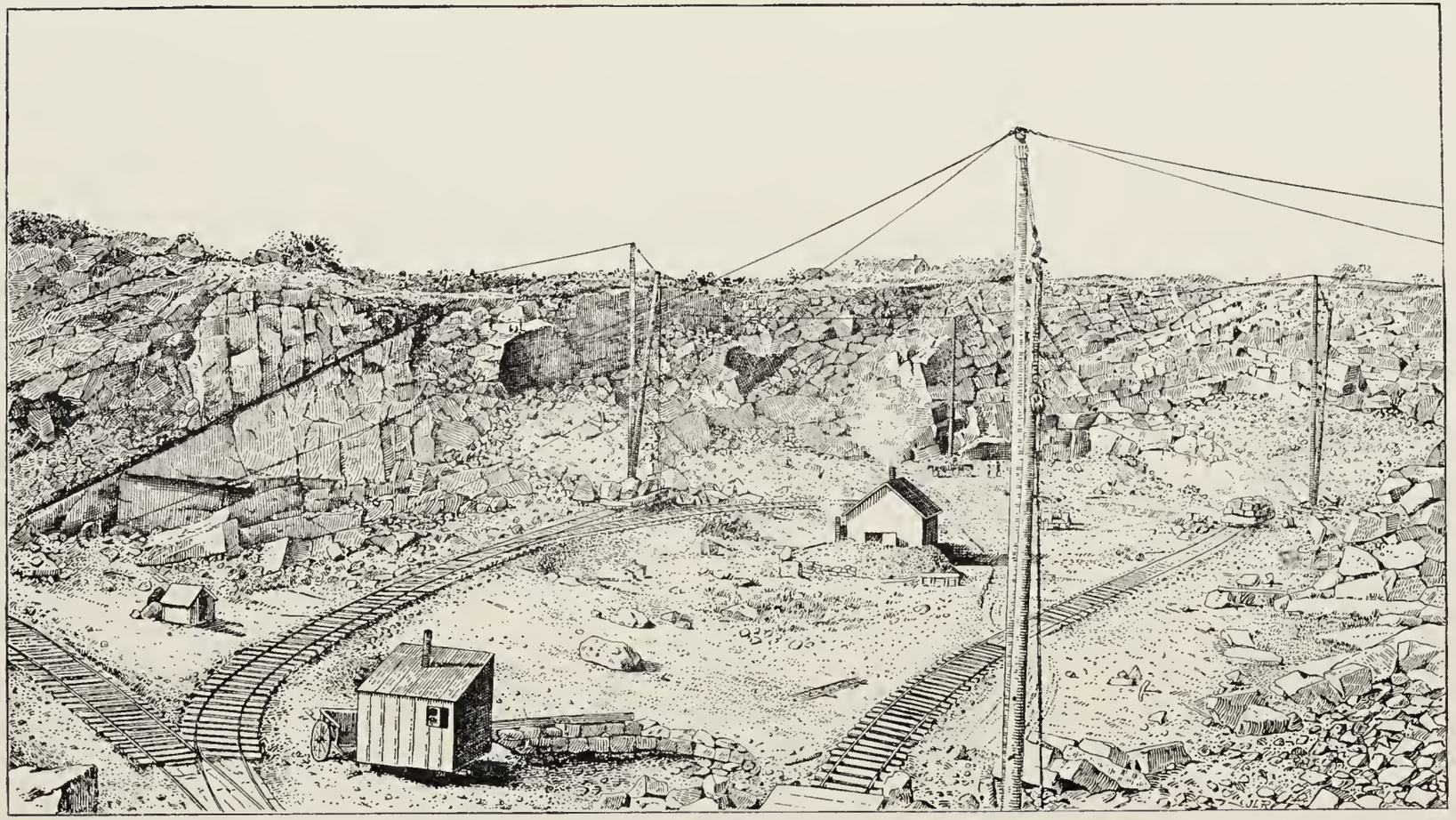
PIGEON HILL QUARRY UPPER PIT, SHOWING EXTREME DEVELOPMENT OF HORIZONTAL JOINTING.

List of dikes of Cape Ann—Continued.

No. on map.	Strike.	Dip.	Width.	Name.	General remarks.
265	N. 53° W		3 to 5 feet.	Diabase	
266	N. 31° W	80° NW	10 to 15°	do	
267	N. 17° E.	50° E.		do	
268	N. 27° W	85° NE.	3½ feet	do	
269	N. 33° to 53° W.		15 feet	Diorite (?)	
270	N. 25° W	70° NE.			
271	N. 13° W	70° E.			
272	N. 31° W		12 feet	Diabase	
273	N. 43° W	80° SW	2 feet	do	
274	N. 23° W	70° NE.	15 feet	do	
275	N. 13° W	75° NE.	15 feet	do	
276	N. 58° W		35 feet	do	
277	N. 58° W		10 feet	Diorite	
278	N. 33° W		15 feet	Diabase	Cuts 276.
279	N. 33° W	90°	18 feet	do	
280	N. 33° W		20 to 25 feet		
281	N. 33° W		3 to 5 feet.	Diabase	
282				do	
283	N. 8° W	75° E.	15 feet	do	
283[a]	N. 1° W	70° E.	1 foot	do	
283[b]	N. 28° W	90°	9 inches	do	
284	N. 77° E.	90°	6 inches	do	
285	N. 63° W	90°	3½ feet	do	Disappears.
286	N. 33° W	90°	3½ feet	do	
287				do	
288	N. 21° W	80° E.	1½ feet		
289	N. 13° W	85° E.	3½ feet		
290	N. 28° W		4 feet	Diabase	
291	N. 9° W	80° NE.	3 feet	do	
292	N. 13° W		3 inches		
293	N. 33° W		12 feet		
294	N. 33° W		12 feet	Diabase	
295	N. 41° W	60° NE.	3 feet+	do	
296	N. 33° W	60° SW	3 feet+	do	
297	N. 9° E.	70° NW	2½ feet	do	
298	N. 43° W	60° NE.	6 feet		
299	N. 63° W	90°	3 feet	Diabase	
300	N. 12° E.	80° NW	3½ feet	do	
301	N. 23° W		3 feet	do	
302	N. 33° W	75° NE.	2 feet 3 inches.	do	
303	N. 48° W		6 feet	do	
304	N. 13° W	85° W.	3 feet	do	
305	N. 28° W			do	
306	N. 13° W	80° E.	15 feet	do	
307	N. 38° W	70° E.	9 feet		
308	N. 62° E.	75° N		Diabase	
309	N. 21° W	90°		do (?)	
310	N. 1° W	90°	2 feet		
311	N. 13° W	90°	3 feet		
312	N. 57° E.	80° NW	3 feet		
313	N. 28° W	90°	3 feet	Diabase	
314	N. 13° W		12 feet		
315	N. 33° W	82° NE.	10 inches	Diabase	

List of dikes of Cape Ann—Continued.

No. on map.	Strike.	Dip.	Width.	Name.	General remarks.
316	N. 35° W	85° W	5½ feet	Diabase	Cuts 317.
317	N. 23° W	75 to 85° E.	3 feet	do	
318	N. 67° W	30° SW	1¼ feet	do	
319	N. 21° W	82° E	2½ feet	do	
320	N. 77° E	65° N	2 feet	do	
321	N. 87° E	68° NE	1 foot	do	
322	N. 88° W	67° NE	21 feet	do	
323	N. 18° W	69° NE	3 feet	do	
324	N. 35° W	84° NE	2 inches	do	
325	N. 8° W	75° NE	1 foot	Porphyritic diabase	
326	N. 22° W	68 to 80° E.	6 feet	do	
327	N. 23° W	48° NE	2 feet	Diabase	
328	N. 8° W	70° NE	2 feet	do	
329	N. 51° W	64° E	4 inches	do	
330	N. 78° E	80° N	3 inches	do	
331	N. 43° W	75° W	1 foot	do	
332	N. 55° W	76° W	1½ feet	do	
333	N. 37° E.	66° N	1 foot	do	Cut by 331 and 332.
334	N. 48° W	75° E	1 foot	do	
335	N. 3° W	90°	1 foot	do	
336	N. 36° W	82° W	3 feet 4 inches.	do	
337	N. 28° W	86° W	3 feet	do	
338	N. 85° W	90°	10 feet	do	
339	N. 46° W	64° NE	2 inches	Porphyritic diabase	
340	N. 66° W	83° NE	2 feet	Diabase	
341	N. 57° E		25 feet	do	
342	N. 5° W	40° NE			
343	N. 53° W	90°	2 feet	Diabase	
344	N. 43° W	90°	1 foot	do	Disappears.
345	N. 22° W	72° E	2 feet	do	
346	N. 28° W	75° NE	2½ feet	do	
347	N. 81° W	65° NE	18 feet	do	
348	N. 3° to 28° W.	83° NE	9 feet	do	Cut by 349.
349	N. 20° E	61° NW	15 inches	Porphyritic diabase	
350	N. 52° E	74° NW	3 inches	Diabase	
351	N. 29° W	86° NE	2 feet	do	
352	N. 11° E	80° NW	6 feet	do	
353	N. 33° W	60° NE	9 feet	do	
354	N. 28° W	90°	2 feet	do	
355	N. 36° W	78° W	1½ feet	do	
356	N. 43° W				
357	N. 43° W	80° E	6 feet		
358	N. 31° W		3 feet		
359	N. 31° W	80° NE	½ to 2½ feet.	Diabase	
360	N. 43° W	70° NE	3 feet	do	
361	N. 28° W	90°	2½ feet	do	
362	N. 13° W	80° NE	3½ feet	do	
363	N. 18° W		6 feet	do	
364	N. 37° W		3 to 4 feet.	do	
365	N. 21° W	60° SW	3 feet	do	
366	N. 16° W	70° W	1½ feet	do	



ROCKPORT GRANITE COMPANY'S QUARRY. SOUTH PIT, SHOWING GENERAL STRUCTURE OF ROCK AND ECONOMIC ORGANIZATION OF THE PIT; LOOKING WEST.

List of observed joint planes.

PIT I.

No. of observation.	Strike.	Dip.	No. of observation.	Strike.	Dip.	No. of observation.	Strike.	Dip.
I.	N. 88° W.	83½° N.	XVII.	N. 71° W.	90° N.	XXXIII.	N. 33° W.	85° NE.
II.	N. 82° W.	90°.	XVIII.	N. 70° W.	84° N.	XXXIV.	N. 24° W.	82° E.
III.	N. 80° W.	88° N.	XIX.	N. 70° W.	86° N.	XXXV.	N. 23° W.	75° E.
IV.	N. 79° W.	83° N.	XX.	N. 69° W.	82° N.	XXXVI.	N. 23° W.	83° E.
V.	N. 79° W.	90°.	XXI.	N. 69° W.	84½° N.	XXXVII.	N. 23° W.	84° E.
VI.	N. 78° W.	85° N.	XXII.	N. 69° W.	88° N.	XXXVIII.	N. 6° W..	83° E.
VII.	N. 78° W.	85° N.	XXIII.	N. 68° W.	84° N.	XXXIX.	N. 5° W..	75° E.
VIII.	N. 76° W.	78° N.	XXIV.	N. 68° W.	88° N.	XL.	N. 3° W..	82° E.
IX.	N. 75° W.	84° N.	XXV.	N. 67° W.	82° N.	XLI.	N. 3° W..	78° E.
X.	N. 74° W.	55° N.	XXVI.	N. 61° W.	81½° N.	XLII.	N. 3° W..	74° E.
XI.	N. 73° W.	78° N.	XXVII.	N. 48° W.	84° NE.	XLIII.	N. 2° W..	75° E.
XII.	N. 73° W.	85° N.	XXVIII.	N. 48° W.	90°.	XLIV.	N. 2° E...	80° W.
XIII.	N. 72° W.	82° N.	XXIX.	N. 47° W.	83° NE.	XLV.	N. 9° E...	83° W.
XIV.	N. 71° W.	86° N.	XXX.	N. 43° W.	85° NE.	XLVI.	N. 40° E..	84° NW.
XV.	N. 71° W.	86° N.	XXXI.	N. 43° W.	88° NE.	XLVII.	N. 47° E..	54° N.
XVI.	N. 71° N .	87° N.	XXXII.	N. 33° W.	80° NE.	XLVIII.	N. 48° E..	54° N.

PIT II.

I.	E. and W.	60° N.	XVI.	N. 24° W.	90°.	XXXI.	N. 8° W..	72° E.
II.	N. 89° W.	73° N.	XVII.	N. 23° W.	85° E.	XXXII.	N. 30° E..	69° NW.
III.	N. 88° W.	90°.	XVIII.	N. 23° W.	84° W.	XXXIII.	N. 32° E..	65° NW.
IV.	N. 87° W.	85° N.	XIX.	N. 23° W.	72° E.	XXXIV.	N. 32° E..	70° NW.
V.	N. 81° W.	84° N.	XX.	N. 23° W.	71° E.	XXXV.	N. 32° E..	72° NW.
VI.	N. 81° W.	83° N.	XXI.	N. 23° W.	65° E.	XXXVI.	N. 32° E..	65° SE.
VII.	N. 79° W.	82° N.	XXII.	N. 23° W.	62° E.	XXXVII.	N. 35° E..	75° NW.
VIII.	N. 77° W.	76° N.	XXIII.	N. 22° W.	85° W.	XXXVIII.	N. 37° E..	70° NW.
IX.	N. 71° W.	80° NE.	XXIV.	N. 22° W.	80° W.	XXXIX.	N. 37° E..	68° SE.
X.	N. 63° W.	74° NE.	XXV.	N. 21° W.	75° E.	XL.	N. 38° E..	70° SE.
XI.	N. 58° W.	80° NE.	XXVI.	N. 21° W.	70° E.	XLI.	N. 85° E..	85° S.
XII.	N. 28° W.	84° W.	XXVII.	N. 21° W.	65° E.	XLII.	N. 86° E..	90°.
XIII.	N. 28° W.	82° W.	XXVIII.	N. 18° W.	79° E.	XLIII.	N. 87° E..	86° S.
XIV.	N. 25° W.	70° NE.	XXIX.	N. 16° W.	81° W.	XLIV.	N. 87° E..	82° S.
XV.	N. 25° W.	69° E.	XXX.	N. 13° W.	80° W.	XLV.	N. 89° E..	58° N.

PIT III.

I.	N. 89° W.	79° N.	XII.	N. 58° W.	80° SW.	XXIII.	N. 27° E..	70° NW.
II.	N. 89° W.	85° S.	XIII.	N. 58° W.	81° SW.	XXIV.	N. 37° E..	63° NW.
III.	N. 88° W.	90°.	XIV.	N. 2° E...	80° NW.	XXV.	N. 42° E..	65° NW.
IV.	N. 88° W.	85° N.	XV.	N. 5° E...	62° NW.	XXVI.	N. 50° E..	68° S.
V.	N. 88° W.	85° N.	XVI.	N. 7° E...	68° NW.	XXVII.	N. 52° E..	55° S.
VI.	N. 88° W.	82° N.	XVII.	N. 12° E..	90° NW.	XXVIII.	N. 62° E..	65° S.
VII.	N. 88° W.	78° N.	XVIII.	N. 12° E..	65° NW.	XXIX.	N. 77° E..	65° S.
VIII.	N. 86° W.	83° N.	XIX.	N. 12° E..	65° NW.	XXX.	N. 82° E..	90°.
IX.	N. 83° W.	85° N.	XX.	N. 12° E..	60° NW.	XXXI.	N. 82° E .	90°.
X.	N. 83° W.	80° N.	XXI.	N. 11° E..	65° NW.	XXXII.	N. 85° E..	76° N.
XI.	N. 81° W.	78° N.	XXII.	N. 22° E..	85° NW.	XXXIII.	N. 87° E..	80° N.

PIT IV.

I.	N. 89° W	82° S.	XII.	N. 58° W.	68° NE.	XXIII.	N. 32° E..	84° NW.
II.	N. 88° W.	78° S.	XIII.	N. 56° W.	70° NE.	XXIV.	N. 32° E..	90°.
III.	N. 88° W.	76° S.	XIV.	N. 43° W.	80° NE.	XXV.	N. 35° E..	90°.
IV.	N. 88° W.	70° S.	XV.	N. 2° E...	55° SE.	XXVI.	N. 35° E..	90°.
V.	N. 88° W.	(?)	XVI.	N. 7° E...	68° SE.	XXVII.	N. 37° E..	90°.
VI.	N. 87° W.	80° S.	XVII.	N. 7° E...	70° NW.	XXVIII.	N. 37° E..	90°.
VII.	N. 86° W.	68° S.	XVIII.	N. 12° E..	45° NW.	XXIX.	N. 37° E..	75° NW.
VIII.	N. 85° W.	75° S.	XIX.	N. 15° E..	55° NW.	XXX.	N. 37° E..	55° SE.
IX.	N. 85° W.	72° S.	XX.	N. 17° E..	64° NW.	XXXI.	N. 39° E..	90°.
X.	N. 85° W.	70° S.	XXI.	N. 22° E..	68° NW.	XXXII.	N. 57° E..	65° NW.
XI.	N. 83° W.	68° S.	XXII.	N. 25° E..	68° NW.			

PIT V.

I.	N. 89° W.	90°.	XIX.	N. 28° W.	60° NE.	XXXVII.	N. 40° E..	55° NW.
II.	N. 88° W.	90°.	XX.	N. 28° W.	65° NE.	XXXVIII.	N. 47° E..	58° NW.
III.	N. 88° W.	80° S.	XXI.	N. 25° W.	55° NE.	XXXIX.	N. 47° E..	54° NW.
IV.	N. 87° W.	90°.	XXII.	N. 23° W.	78° NE.	XL.	N. 65° E..	90°.
V.	N. 63° W.	55° NE.	XXIII.	N. 23° W.	42° SW.	XLI.	N. 67° E..	84° S.
VI.	N. 58° W.	62° NE.	XXIV.	N. 18° W.	85° NE.	XLII.	N. 77° E..	85° S.
VII.	N. 55° W.	85° NE.	XXV.	N. 18° W.	68° NE.	XLIII.	N. 77° E..	65° N.
VIII.	N. 53° W.	76° NE.	XXVI.	N. 15° W.	80° NW.	XLIV.	N. 77° E..	40° S.
IX.	N. 51° W.	58° NE.	XXVII.	N. 10° W.	90°.	XLV.	N. 82° E..	90°.
X.	N. 48° W.	77° NE.	XXVIII.	N. 8° W..	90°.	XLVI.	N. 83° E..	90°.
XI.	N. 48° W.	44° NE.	XXIX.	N. 5° W..	90°.	XLVII.	N. 84° E..	90°.
XII.	N. 46° W.	70° NE.	XXX.	N. 5° W..	90°.	XLVIII.	N. 85° E..	90°.
XIII.	N. 41° W.	45° NE.	XXXI.	N. 3° W..	90°.	XLIX.	N. 85° E..	90°.
XIV.	N. 40° W.	48° NE.	XXXII.	N. 3° W..	40° E.	L.	N. 87° E..	90°.
XV.	N. 33° W.	79° NE.	XXXIII.	N. 7° E...	58° NW.	LI.	N. 87° E..	83° S.
XVI.	N. 33° W.	72° NE.	XXXIV.	N. 7° E...	55° NW.	LII.	N. 88° E..	68° NW.
XVII.	N. 33° W.	38° SW.	XXXV.	N. 27° E..	85° SE.	LIII.	N. 89° E..	70° NW.
XVIII.	N. 30° W.	74° NE.	XXXVI.	N. 31° E..	82° SE.			

PIT VI.

I.	N. 81° W.	90°.	XVII.	N. 25° W.	60° SW.	XXXII.	N. 57° E..	82° S.
II.	N. 56° W.	63° NE.	XVIII.	N. 23° W.	72° NE.	XXXIII.	N. 67° E..	85° N.
III.	N. 53° W.	40° NE.	XIX.	N. 23° W.	65° E.	XXXIV.	N. 67° E..	82° S.
IV.	N. 53° W.	38° SW.	XX.	N. 23° W.	62° E.	XXXV.	N. 69° E..	75° S.
V.	N. 51° W.	64° NE.	XXI.	N. 22° W.	65° E.	XXXVI.	N. 71° E..	83° S.
VI.	N. 48° W.	44° SW.	XXII.	N. 21° W.	70° E.	XXXVII.	N. 72° E..	78° S.
VII.	N. 46° W.	60° SW.	XXIII.	N. 18° W.	60° E.	XXXVIII.	N. 75° E..	73° S.
VIII.	N. 45° W.	74° NE.	XXIV.	N. 13° W.	71° E.	XXXIX.	N. 77° E..	84° NW.
IX.	N. 43° W.	83° NE.	XXV.	N. 3° W..	70° E.	XL.	N. 78° E..	80° NW.
X.	N. 43° W.	75° NE.	XXVI.	N. and S.	54° W.	XLI.	N. 79° E..	90°.
XI.	N. 43° W.	80° SW.	XXVII.	N. 2° E...	55° W.	XLII.	N. 79° E..	90°.
XII.	N. 42° W.	82° SW.	XXVIII.	N. 27° E..	90°.	XLIII.	N. 81° E..	90°.
XIII.	N. 41° W.	84° SW.	XXIX.	N. 32° E..	52° NW.	XLIV.	N. 82° E..	90°.
XIV.	N. 41° W.	82° NE.	XXX.	N. 47° E..	60° NW.	XLV.	N. 83° E..	90°.
XV.	40° W.	68° NE.	XXXI.	N. 47° E..	50° NW.	XLVI.	N. 84° E..	90°.
XVI.	31° W.	39° SW.						

ROCKPORT GRANITE COMPANY'S MIDDLE QUARRY SHOWING FOLDINGS OF GRANITITE AT CONTACT WITH DIKE; LOOKING WEST.

PIT VII.

I.	N. 33° W.	85° W.	XIV.	N. 2° E...	80° NW.	XXVII.	N. 34° E..	70° NW.
II.	N. 28° W.	90°.	XV.	N. 5° E...	80° NW.	XXVIII.	N. 35° E..	72° NW.
III.	N. 28° W.	61° W.	XVI.	N. 7° E...	78° NW.	XXIX.	N. 35° E..	58° NW.
IV.	N. 27° W.	60° W.	XVII.	N. 7° E...	64° NW.	XXX.	N. 37° E .	90°.
V.	N. 24° W.	84° W.	XVIII.	N. 15° E..	74° NW.	XXXI.	N. 37° E..	65° NW.
VI.	N. 23° W.	60° W.	XIX.	N. 25° E..	76° NW.	XXXII.	N. 39° E.	90°.
VII.	N. 17° W.	85° E.	XX.	N. 25° E..	70° NW.	XXXIII.	N. 72° E..	77° S.
VIII.	N. 17° W.	80° W.	XXI.	N. 27° E..	68° NW.	XXXIV.	N. 77° E..	90°.
IX.	N. 14° W.	90°.	XXII.	N. 29° E..	80° NW.	XXXV.	N. 77° E..	49° S.
X.	N. 13° W.	76° W.	XXIII.	N. 29° E..	68° NW.	XXXVI.	N. 82° E..	75° N.
XI.	N. 3° W..	60° W.	XXIV.	N. 31° E..	90°.	XXXVII.	N. 87° E .	90°.
XII.	N. 1° W..	78° W.	XXV.	N. 32° E..	90°.	XXXVIII.	N. 87° E..	90°.
XIII.	N. 2° E...	82° NW.	XXVI.	N. 34° E..	90°.			

PIT VIII.

I.	N. 58° W.	84° NE.	V.	N. 33° W.	72° SW.	VIII.	N. 52° E.	80° NW.
II.	N. 53° W.	60° SW.	VI.	N. 47° E..	80° N.	IX.	N. 54° E..	79° NW.
III.	N. 45° W.	65° NE.	VII.	N. 48° E..	79° NW.	X.	N. 59° E..	75° NW.
IV.	N. 38° W.	75° NE.						

PIT IX.

I.	N. 75° W.	83° SE.	IX.	N. 51° E .	90°.	XV.	N. 60° E..	72° NW.
II.	N. 71° W.	82° SE.	X.	N. 51° E..	78° SW.	XVI.	N. 63° E..	81° N.
III.	N. 65° W.	75° E.	XI.	N. 55° E..	77° N.	XVII.	N. 65° E..	74° N.
IV.	N. 61° W.	80° E.	XII.	N. 57° E..	80° N.	XVIII.	N. 69° E..	79° N.
VI.	N. 28° W.	70° E.	XIII.	N. 59° E.	90°.	XIX.	N. 70° E..	78° SE.
VII.	N. 25° W.	70° E.	XIV.	N. 59° E..	80° S.	XX.	N. 71° E.	71° S.
VIII.	N. 23° W.	71° E.						

PIT X.

I.	N. 76° W.	83° N.	VIII.	N. 31° E..	70° NW.	XV.	N. 70° E.	72° S.
II.	N. 76° W.	76° N.	IX.	N. 34° E..	67° NW.	XVI.	N. 70° E.	75° S.
III.	N. 32° W.	83° E.	X.	N. 47° E..	81° NW.	XVII.	N. 71° E..	54° N.
IV.	N. 23° W.	90°.	XI.	N. 48° E..	83° SE.	XVIII.	N. 75° E..	70° S.
V.	N. 15° W.	80° SW.	XII.	N. 66° E..	81° S.	XIX.	N. 77° E..	73° S.
VI.	N. 10° E..	45° NW.	XIII.	N. 69° E..	70° S.	XX.	N. 84° E..	90°.
VII.	N. 27° E..	70° SE.	XIV.	N. 70° E..	83° S.	XXI.	N. 86° E..	82° S.

PIT XI.

I.	E. and W.	90°.	IX.	N. 52° W	87° SW.	XVI.	N. 32° E..	90°.
II.	N. 83° W.	90°.	X.	N. 52° W.	70° NE	XVII.	N. 32° E..	80° NW.
III.	N. 66° W.	83° N.	XI.	N. 52° W.	87° SW.	XVIII.	N. 34° E.	81° SE.
IV.	N. 61° W.	48° NE.	XII.	N. 48° W.	82° NE.	XIX.	N. 37° E..	62° NW.
V.	N. 58° W.	80° NE.	XIII.	N. 46° W.	90°.	XX.	N. 39° E..	75° N.
VI.	N. 56° W.	80° NE.	XIV.	N. 2° E...	64° E.	XXI.	N. 47° E..	65° NW.
VII.	N. 54° W.	87° NE.	XV.	N. 22° E..	64° NW.	XXII.	N. 49° E..	80° SE.
VIII.	N. 53° W.	90°.						

PIT XII.

I.	N. 83° W.	73° SW.	XVIII.	N. 23° W.	90°.	XXXV.	N. 29° E..	85° NW.
II.	N. 75° W.	73° NE.	XIX.	N. 13° W.	54° W.	XXXVI.	N. 30° E..	83° NW.
III.	N. 67° W.	85° NE.	XX.	N. 3° W..	58° NW.	XXXVII.	N. 32° E..	83° NW.
IV.	N. 66° W.	90°.	XXI.	N. 1° W..	64° NW.	XXXVIII.	N. 32° E..	63° NW.
V.	N 66° W.	76° NE.	XXII.	N. 2° E...	71° SW.	XXXIX.	N. 34° E	68° NW.
VI.	N. 66° W.	64° NE.	XXIII.	N. 9° E...	60° NW.	XL.	N. 37° E..	90°.
VII.	N. 63° W.	83° N.	XXIV.	N. 12° E..	60° NW.	XLI.	N. 37° E.	76° NW.
VIII.	N. 60° W	90°.	XXV.	N. 17° E.	64° NW.	XLII.	N. 39° E..	90°.
IX.	N. 58° W.	88° NE.	XXVI.	N. 17° E..	78° NW.	XLIII.	N. 39° E..	62° NW.
X.	N. 56° W.	83° NE.	XXVII.	N. 20° E..	78° NW.	XLIV.	N. 40° E..	86° NW.
XI.	N. 53° W.	81° NE.	XXVIII.	N. 20° E..	62° NW.	XLV.	N. 41° E .	90°.
XII.	N. 53° W.	78° SW.	XXIX.	N. 22° E..	69° SE.	XLVI.	N. 41° E..	73° NW.
XIII.	N. 46° W.	70° NE.	XXX.	N. 24° E..	90°.	XLVII.	N. 41° E.	58° NW.
XIV.	N. 45° W.	75° NE.	XXXI.	N. 25° E..	84° NW.	XLVIII.	N. 42° E..	90°.
XV.	N. 44° W.	80° NE.	XXXII.	N. 26° E..	90°.	XLIX.	N. 48° E..	78° NW.
XVI.	N. 36° W.	68° NE.	XXXIII.	N. 26° E..	65° NW.	L.	N. 62° E..	83° NW.
XVII.	N. 33° W.	73° NE.	XXXIV.	N. 27° E..	83° NW.	LI.	N. 66° E..	90°.

PIT XIII.

I.	N. 86° W.	75° NE.	IX.	N. 30° W.	87° NE.	XVI.	N. 20° E..	71° NW.
II.	N. 84° W.	76° NE.	X.	N. 28° W.	70° NE.	XVII.	N. 22° E..	84° SE.
III.	N. 83° W.	80° NE.	XI.	N. 12° W.	80° NE.	XVIII.	N. 28° E..	78° SE.
IV.	N. 38° W.	73° NE.	XII.	N. 8° W..	78° NE.	XIX.	N 30° E..	78° SE.
V.	N. 36° W.	78° NE.	XIII.	N. 17° E..	80° SE.	XX.	N. 48° E..	80° SE.
VI.	N. 34° W.	85° NE.	XIV.	N. 17° E..	73° SE.	XXI.	N. 67° E..	90°.
VII.	N. 33° W.	75° NE.	XV.	N. 20° E..	83° SE.	XXII.	N. 73° E..	75° S.
VIII.	N. 31° W.	81° NE.						

PIT XIV.

I.	N. 39° W.	87° NE.	XV.	N. 34° E..	68° NW.	XXIX.	N. 59° E..	90°.
II.	N. 35° W.	90°.	XVI.	N. 35° E..	90°.	XXX.	N. 59° E.	90°.
III.	N. 33° W.	90°.	XVII.	N. 37° E..	83° NW.	XXXI.	N. 60° E..	90°.
IV.	N. 18° W.	90°.	XVIII.	N. 40° E..	90°.	XXXII.	N. 61° E..	79° NW.
V.	N. 25° E..	90°.	XIX.	N. 40° E..	84° NW.	XXXIII.	N. 62° E..	82° NW.
VI.	N. 28° E..	70° NW.	XX.	N. 40° E..	78° NW.	XXXIV.	N. 63° E..	90°.
VII.	N. 30° E..	84° SE.	XXI.	N. 40° E..	73° NW.	XXXV.	N. 67° E..	78° SE.
VIII.	N. 31° E.	78° NW.	XXII.	N. 41° E..	74° NW.	XXXVI.	N. 71° E..	90°.
IX.	N. 32° E..	90°.	XXIII.	N. 47° E..	88° NW.	XXXVII.	N. 75° E.	90°.
X.	N. 32° E..	90°.	XXIV.	N. 47° E.	72° NW.	XXXVIII.	N. 77° E..	83° SE.
XI.	N. 32° E..	85° NW.	XXV.	N. 48° E..	90°.	XXXIX.	N. 77° E..	82° SE.
XII.	N. 32° E..	75° NW.	XXVI.	N. 49° E..	75° NW.	XL.	N. 83° E..	80° S.
XIII.	N. 32° E..	73° NW.	XXVII.	N. 50° E..	90°.	XLI.	N. 84° E..	83° N.
XIV.	N. 34° E..	78° NW.	XXVIII.	N. 58° E..	82° NW.	XLII.	N 87° E..	85° N.

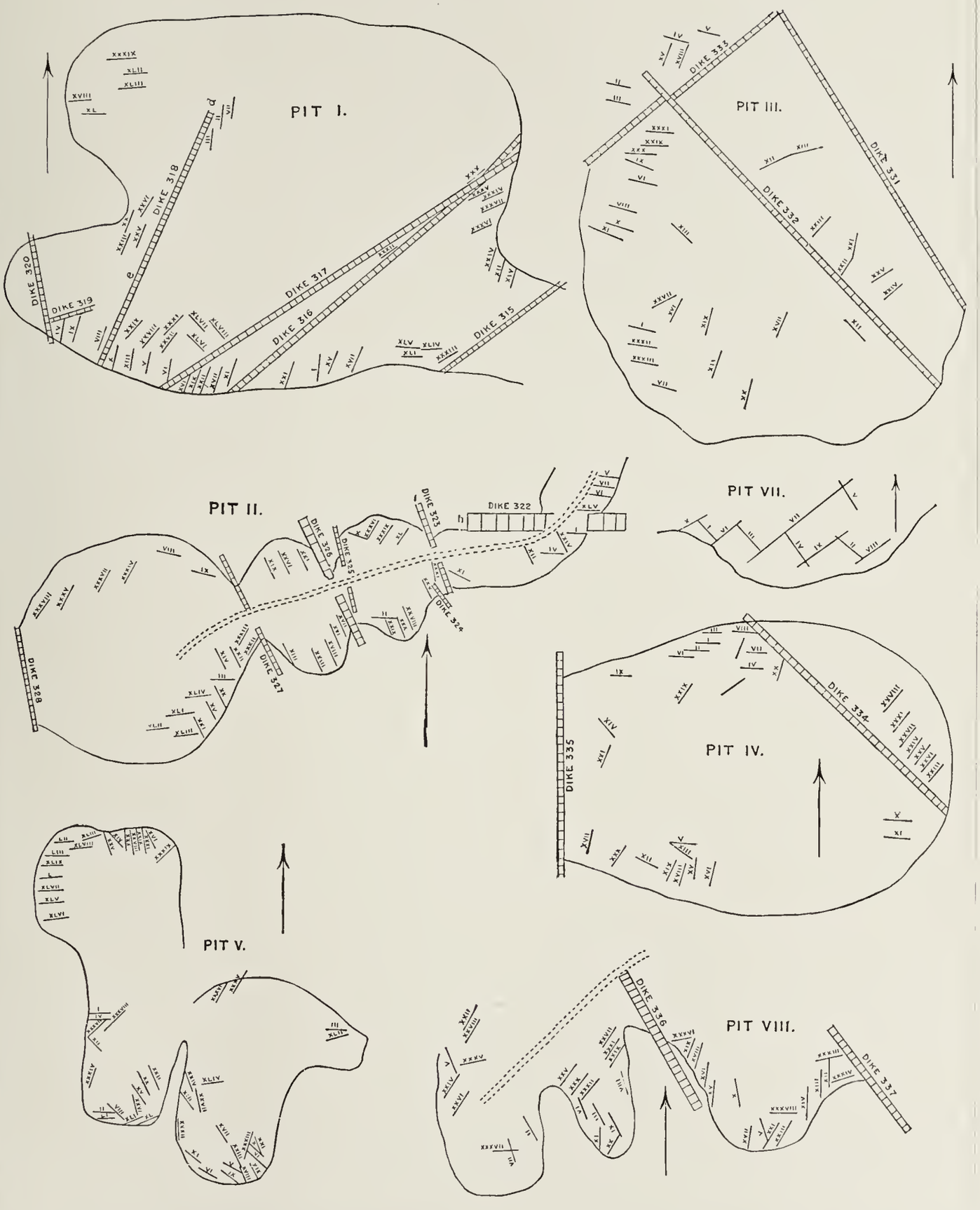


DIAGRAM SHOWING DISTRIBUTION OF DIKES AND JOINTS.

PIT XV.

I.	N. 89° W.	90°.	XIV.	N. 32° W.	73° NE.	XXVII.	N. 47° E..	90°.
II.	N. 88° W.	48 to 73° S	XV.	N. 32° W.	72° NE.	XXVIII.	N. 47° E..	90°.
III.	N. 86° W.	83° S.	XVI.	N. 31° W.	75° NE.	XXIX.	N. 47° E..	90°.
IV.	N. 83° W.	90°.	XVII.	N. 31° W.	70° NE.	XXX.	N. 48° E..	90°.
V.	N. 83° W.	90°.	XVIII.	N. 28° W.	73° SW.	XXXI.	N. 50° E..	90°.
VI.	N. 73° W.	85° SW.	XIX.	N. 28° W.	71° NE.	XXXII.	N. 50° E..	90°.
VII.	N. 41° W.	73° NE.	XX.	N. 28° W.	82° NE.	XXXIII.	N. 52° E..	90°.
VIII.	N. 39° W.	72° NE.	XXI.	N. 25° W.	70° E.	XXXIV.	N. 57° E..	90°.
IX.	N. 37° W.	70° NE.	XXII.	N. 23° W.	83° E.	XXXV.	N. 62° E..	90°.
X.	N. 35° W.	78° NE.	XXIII.	N. 19° W.	82° E.	XXXVI.	N. 77° E..	90°.
XI.	N. 33° W.	75° NE.	XXIV.	N. 32° E..	81° SE.	XXXVII.	N. 82° E..	80° SW.
XII.	N. 33° W.	73° NE.	XXV.	N. 42° E..	80° NW.	XXXVIII.	N. 89° E..	90°.
XIII.	N. 33° W.	72° NE.	XXVI.	N. 45° E..	90°.	XXXIX.	N. 89° E..	90°.

PIT XVI.

I.	N. 86° W.	82° N.	XI.	N. 25° W.	60° SW.	XXI.	N. 34° E..	70° NW.
II.	N. 86° W.	78° N.	XII.	N. 23° W.	78° SW.	XXII.	N. 36° E..	65° NW.
III.	N. 83° W.	82° N.	XIII.	N. 11° E..	65° NW.	XXIII.	N. 37° E..	80° NW.
IV.	N. 83° W.	80° N.	XIV.	N. 17° E..	62° NW.	XXIV.	N. 37° E..	72° NW.
V.	N. 81° W.	81° N.	XV.	N. 18° E..	80° NW.	XXV.	N. 37° E..	70° NW.
VI.	N. 28° W.	78° SW.	XVI.	N. 22° E..	63° NW.	XXVI.	N. 38° E..	70° NW.
VII.	N. 28° W.	71° SW.	XVII.	N. 23° E..	69° NW.	XXVII.	N. 39° E..	62° NW.
VIII.	N. 28° W.	70° SW.	XVIII.	N. 30° E..	70° NW.	XXVIII.	N. 70° E..	85° NW.
IX.	N. 26° W.	58° SW.	XIX.	N. 32° E..	70° NW.	XXIX.	N. 88° E.	80° N.
X.	N. 25° W.	75° SW.	XX.	N. 34° E..	75° NW.	XXX.	N. 89° E..	80° N.

PIT XVII.

I.	N. 81° W.	90°.	XII.	N. 23° W.	90°.	XXIII.	N. 16° E..	75° NW.
II.	N. 81° W.	87° N.	XIII.	N. 16° W.	90°.	XXIV.	N. 17° E..	83° NW.
III.	N. 80° W.	90°.	XIV.	N. 14° W.	90°.	XXV.	N. 17° E..	81° NW.
IV.	N. 80° W.	90°.	XV.	N. 7° E...	75° NW.	XXVI.	N. 17° E..	70° NW.
V.	N. 78° W.	90°.	XVI.	N. 11° E..	88° NW.	XXVII.	N. 17° E..	69° NW.
VI.	N. 78° W.	85° N.	XVII.	N. 11° E..	83° NW.	XXVIII.	N. 20° E..	90°.
VII.	N. 76° W.	90°.	XVIII.	N. 11° E..	81° NW.	XXIX.	N. 20° E..	71° SE.
VIII.	N. 73° W.	85° N.	XIX.	N. 12° E..	78° NW.	XXX.	N. 22° E..	85° NW.
IX.	N. 37° W.	80° NE.	XX.	N. 14° E..	80° NW.	XXXI.	N. 73° E..	90°.
X.	N. 25° W.	90°.	XXI.	N. 14° E..	80° NW.	XXXII.	N. 74° E..	90°.
XI.	N. 25° W.	84° E.	XXII.	N. 15° E..	78° NW.	XXXIII.	N. 77° E..	85° SE.

PIT XVIII.

I.	N. 88° W.	81° N.	XII.	N. 11° E..	68° NW.	XXIII.	N. 48° E..	60° NW.
II.	N. 88° W.	90°.	XIII.	N. 12° E..	60° NW.	XXIV.	N. 57° E..	83° SE.
III.	N. 88° W.	79° S.	XIV.	N. 17° E..	73° NW.	XXV.	N. 62° E..	90°.
IV.	N. 86° W.	85° S.	XV.	N. 17° E..	61° NW.	XXVI.	N. 64° E..	75° SE.
V.	N. 84° W.	84° S.	XVI.	N. 17° E..	60° NW.	XXVII.	N. 67° E..	90°.
VI.	N. 82° W.	80° S.	XVII.	N. 18° E..	61° NW.	XXVIII.	N. 86° E..	75° S.
VII.	N. 63° W.	81° S.	XVIII.	N. 19° E..	75° NW.	XXIX.	N. 87° E..	76° S.
VIII.	N. 28° W.	60° NE.	XIX.	N. 20° E..	65° NW.	XXX.	N. 87° E..	68° S.
IX.	N. 18° W.	90°.	XX.	N. 20° E..	65° NW.	XXXI.	N. 89° E..	90°.
X.	N. 15° W.	80° SE.	XXI.	N. 27° E..	69° NW.	XXXII.	N. 89° E..	81° S.
XI.	N. 7° E...	63° NW.	XXII.	N. 30° E..	60° NW.			

PIT XIX.

I.	N. 89° W.	90°.	VIII.	N. 33° W.	68° NE.	XV.	N. 7° E...	75° S.
II.	N. 68° W.	68° SW.	IX.	N. 31° W	70° NE.	XVI.	N. 47° E..	63° NW.
III.	N. 67° W.	81° SW.	X.	N. 25° W.	67° NE.	XVII.	N. 48° E..	62° NW.
IV.	N. 66° W.	71° SW.	XI.	N. 23° W.	64° NE.	XVIII.	N. 66° E..	68° NW.
V.	N. 63° W.	78° SW.	XII.	N. 23° W.	63° NE.	XIX.	N. 67° E..	72° SE.
VI.	N. 63° W.	70° SW.	XIII.	N. 23° W.	63° NE.	XX.	N. 82° E..	64° S.
VII.	N. 34° W.	61° NE.	XIV.	N. 23° W.	58° NE.			

PIT XX.

I.	N. 78° W.	62° NE.	VI.	N. 1° W..	75° E.	X.	N. 67° E..	82° N.
II.	N. 73° W.	55° SW.	VII.	N. 2° E...	90°.	XI.	N. 69° E..	82° N.
III.	N. 58° W.	78° SW.	VIII.	N. 2° E..	65° SE.	XII.	N. 70° E..	85° N.
IV.	N. 33° W.	73° SW.	IX.	N. 49° E.	60° NW.	XIII.	N. 77° E..	74° N.
V.	N. 7° W..	90°.						

RIFTING OF THE QUARRIED ROCKS.

The quarried rocks of Cape Ann exhibit, as do those in other parts of the country, the phenomenon of "rifting" in an interesting manner. It is owing to the existence of this feature that the imperfectly jointed rocks of this region are so serviceable to the quarryman. By the term "rift" is indicated an incipient fracture in the rock which has not developed in the form of a joint plane. No very distinct passage has been seen between the incipient fracture of the rifting and the perfect joint planes. At one point between the two great quarries at Bay View, where the rift has been subjected to the action of the weather on the old glacial surface or on a surface which has been for some time bared to the weather, the rifting appears as visible fractures, not averaging more than a quarter of an inch apart and extending for a distance of two feet through the rock. In yet other cases, joints which have a development of chloritic and epidotic material on the side of the fracture, known to the quarrymen as "green seams," pass rather more distinctly into the rift planes than do the ordinary joints.

Quarrymen, for convenience of description, divide the rift lines along which their rock fractures into two divisions, which are generally found in quarries, viz, the "rift" and the "cut-off." The most manifest of these, whatever be the direction, they term the rift. A set of joints at an angle of about 65 degrees to the rift they call the "cut-off." Sometimes a third system of incipient fractures is found nearly horizontal, which they term "lift." No other planes of fractures save those three are found in the granites of Cape Ann. Indeed, the third line of fracture is more frequently absent than present.

The peculiar feature of all these incipient fractures is that they appear only where the rock has been exposed to the weather or to

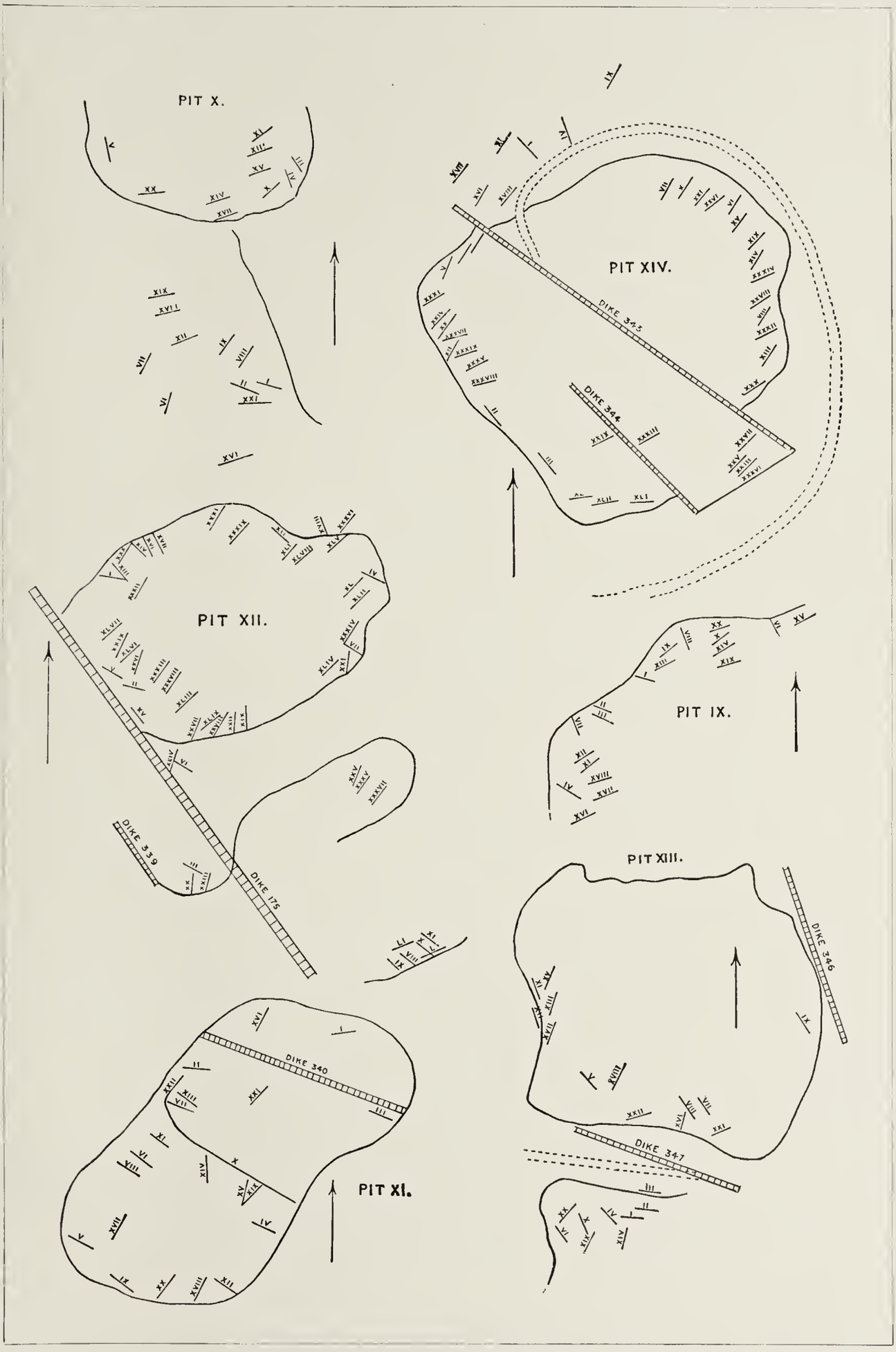


DIAGRAM SHOWING DISTRIBUTION OF DIKES AND JOINTS.

strain, while the joints, though not readily visible, appear evident on close inspection as far as the tendency to split on their planes extends.

When broken along the rift planes the faces of the fracture are much rougher than the faces exhibited by the deeper joint planes. This at first sight seemed to indicate that the character of the fractures and faults was essentially different from that artificially developed on the rift lines. It may be, however, that the processes of decay and replacement brought about by the action of the weather along the joint planes has caused this difference. It is also noticeable that where the rock is broken across the rift axes it commonly assumes the conchoidal fracture, and has in all cases the surface much more rough than that of the fractures which have developed along the rift planes. This is evidently due to the fact that in the conchoidal fracture the splitting turns around the crystals more than it does when the splitting is along the rift.

Although it is not yet certainly the case, it seems likely that there is a relation of a genetic sort between these fractures of the rift and those which are expressed in recognizable joint planes. In some of the quarries there is a manifest connection between the two. Thus in the Bay View quarries the most evident rift agrees exactly in direction with the most conspicuous set of joint planes. Elsewhere the relation can not be so well made out. It may be also noted that in one case the most evident rift plane on one side of a dike appeared to be indicated but extinguished on the other side of the intrusion.

Microscopic examination shows that the rifting probably occurs under the following conditions: The mass of granite, like that of other holo-crystalline rocks, is made up of material, all of which is arranged with reference to definite crystalline axes, but these axes are disposed in an entirely irregular manner. These crystals each have planes on which breakage will more readily occur than on other lines. Now, some of these crystals, the feldspar and hornblende at least, have lines along which they fracture with certain readiness. Such fracture planes are not known to exist with quartz, but it may also have axes on which breakage is somewhat more easy than in other planes. Moreover, in all these crystals, whatever the shape of their periphery, the line of juncture with the neighboring crystals is always somewhat irregular. Now, if a mass of this rock by strains is urged to fracture, the plane of rupture will be formed at some points by breaking through the crystal along its line of weakness, and in a general way coincide with the run of the rupture plane. In other cases the rupture will follow around the adjacent faces of the crystals. Microscopic sections show that something like this action has taken place. Along the lines of the rift where they cut through a feldspar crystal, although the evidence of displacement is obscure, the existence of a rupture is shown by the presence of a

distinct fault breccia, the fragments of the breccia having been afterwards cemented together with quartz, or, perhaps, by other minerals.

It seems likely that the amount of dislocation attendant on the formation of these fractures is extremely small, but this amount has not yet been determined. It seems also probable in all cases that the fracture is practically closed by the secretion of cement, which has bound the walls together. It may well have been that these several separate sets of fractures, those of the rift, the cut-off, and lift, were formed at different times, and were in turn more or less completely healed by exudations from the walls. Although these walls are at least in part fixed together, when the quarryman disrupts the mass, fractures more readily occur along these old planes than in any other direction.

The difficulty in identifying the rift structure with the joint planes arises from the fact that the joint planes are generally remote from each other in a far greater degree than those of the rifts, there being, in effect, no passage between the two classes of ruptures. If joint planes are genetically connected with rift planes, then it must have been that by the application of some force after the rifts were formed certain of the fracture lines at remote intervals were by secondary strains developed into joints.

Even if we could account, as it seems likely we may, for certain of the joint planes on this hypothesis, there remain, as the foregoing statements concerning joints show, many others which can not be referred to planes of rifting. It seems pretty clear that there is not an indefinite number of rift planes in the mass of the rock, while the number of positions of the joint planes is practically indefinite. Although the rift planes exist in a great portion of the rocks of Cape Ann there are some considerable irregularly disposed areas in the quarries, which appear in good part, if not entirely, destitute of these potential fracture lines. So far it has not been possible to secure any clue as to the relations of these non-rifted areas.

There is a practical point which comes out of this consideration concerning the value of rifts and joints to the quarryman's work. In general the joint planes of our crystalline rocks are disadvantageous to the quarryman. In certain cases they serve his needs, but oftener with a number of these fracture lines they break up the rock into inconvenient forms. Moreover, the joint planes, even where useful, are apt to become less distinct as depth is attained. On the other hand, the rift, though variable in amount and direction, appears to be a permanent feature in granitic rocks, and on the relation of the planes to each other depends in a large measure the serviceability of the material for architectural purposes. It therefore is well for persons undertaking costly work, connected with the stripping away of parts of the rock which are affected by water and other

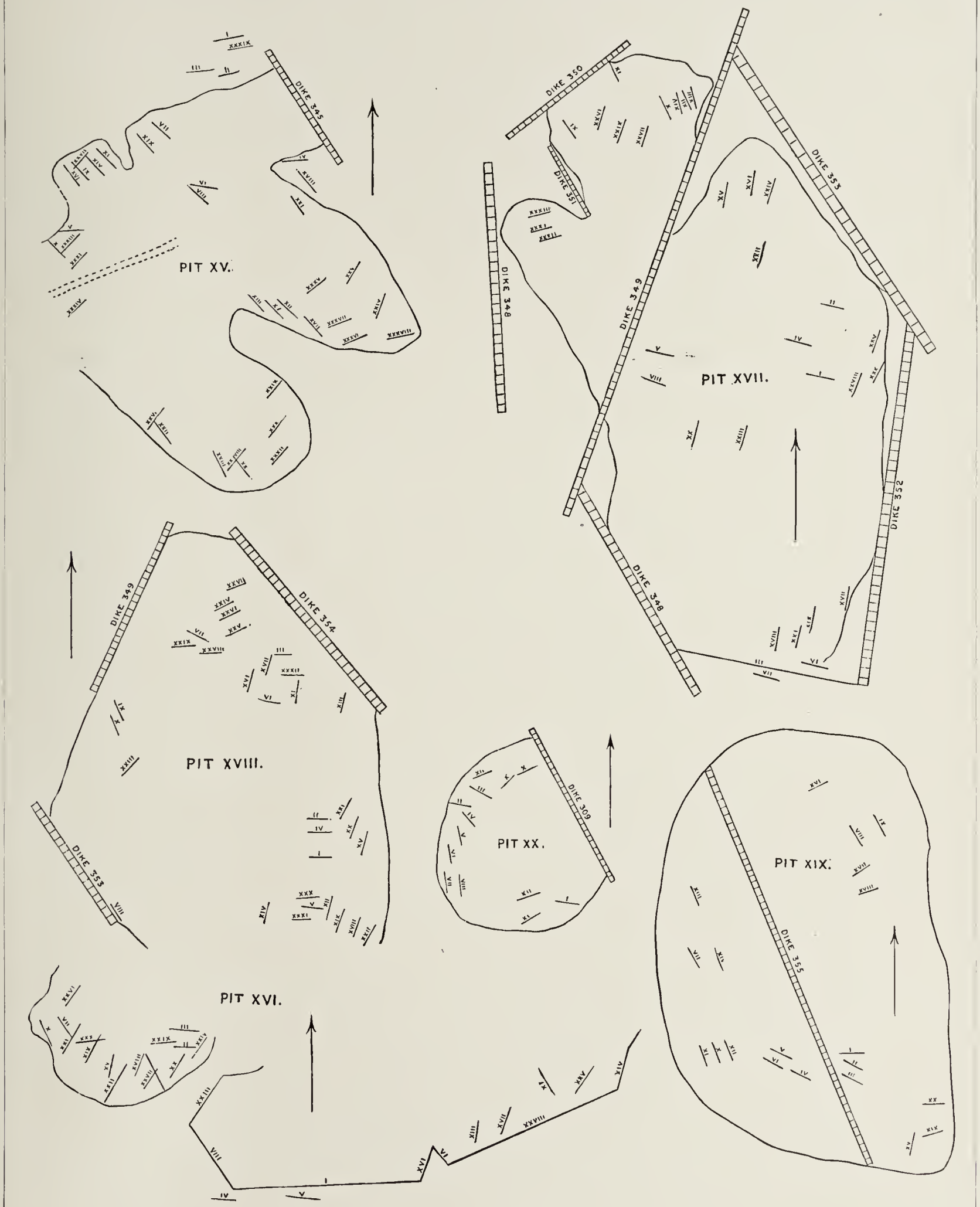


DIAGRAM SHOWING DISTRIBUTION OF DIKES AND JOINTS.

agents of superficial decay, to determine the character of the incipient rift fractures with reference to the end in view.

THE GENERAL PETROGRAPHY OF CAPE ANN.

The bed rock on the island of Cape Ann is mainly granite cut in various directions by diabase and other dikes. This granite has been studied by several geologists, and has been called syenite, granite, and granitite. Dr. M. E. Wadsworth, who has made the most careful petrographic studies in this region, has decided the rock to be hornblendic granitite, and the studies made in preparation for this report point to the same conclusion. In a dozen microscopic slides cut from specimens collected at various points on the island a very nearly uniform character is observed. Quartz and orthoclase feldspar form the bulk of the rock, with black hornblende and biotite as the two other essential constituents. The feldspar is often microline. Both the quartz and feldspar are very much strained and broken, exhibiting distinct lines of weakness which develop the rift of the rock.

Besides these essential minerals we find the usual accessories of granite, plagioclase feldspar, magnetite, limonite, chlorite, apatite, zircon, epidote, and fluorite. The mineral danalite, which Dr. J. P. Cooke described from Rockport, also occasionally occurs. It resembles garnet in the slide, as well as when macroscopically examined.

All the quarries on Cape Ann are in rock having a uniform character as above described. At those exposures the biotite and hornblende vary somewhat in abundance; but aside from this there is very little local modification in the character of the rock. On the sea shore, however, we observe that there are considerable variations in its texture and composition. In some places it is very fine grained; again it becomes extremely coarse and almost porphyritic. In some cases the granite weathers easily; in others it is very durable. The rock often becomes very syenitic, and in one locality, in a railroad cut on the Eastern Railroad line, near the Magnolia station, the almost total absence of free quartz makes the rock, at least locally, a true syenite. It is possible that in some cases these variations may be caused by injections of granitic dikes through the bed rock; although in no case has it been possible to prove this hypothesis.

The islands lying near the shore—Milk, Salvages and Thatcher's—present a more difficult problem. Their complete isolation from the main mass and separation by a rather deep trough may indicate a line of weakness occupied by some more easily eroded rock, or perhaps may represent the line of contact of two distinct granitic injections. The petrographic evidence on this point is not complete. The bed rock on these several islands, while being essentially the same, differs widely in character from that on the mainland. Whether this

be due simply to local variations in the Cape Ann mass, or whether it marks a distinct ejection, has not been determined.

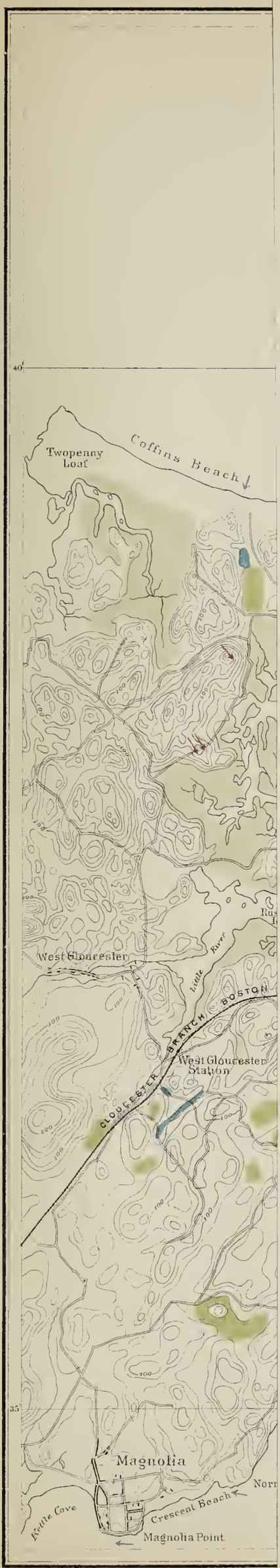
Macroscopically, the rock on the above-named islands differs from that on Cape Ann in being much darker, in the greater abundance of hornblende and magnetite, in containing much less quartz, and in having a darker colored feldspar. Quartz is quite common as minute crystalloids, and the feldspar often occurs in the form of Carlsbad twins and as microline. The general absence of macroscopic quartz is sufficiently well marked to place the rock among the syenitic granites. There is a frequent tendency to the porphyritic character. No distinction between these rocks has been made in the accompanying map of the bed rock.

In the vicinity of Squam River an area of diorite has been found occupying the position indicated upon the map. The depression occupied by Squam River is one of the most marked features in the topography of the region. On either side are high hills, and the center of the Reach is considerably below sea level, although it is much encumbered by glacial drift. To explain this valley was for a long time a difficult problem. It appeared quite evident that it must indicate a line of weakness in the granitite, though the nature of this remained undetermined. The general agreement between the trend of the valley, and the strike of the principal set of dikes and their abundance in that vicinity, suggested an explanation which lacked proof. For some time the presence of this diorite was unperceived, and it was considered a mere fine grained variation of the Cape Ann granitite.

This diorite is very light colored, has a very glassy feldspar and some quartz, so that until the microscope was used its true character was undiscovered. The rock is finer grained than the granitite, is a trifle darker, and has a much more complicated development of joint planes. Instead of the great massive jointing so typical of granitite, the rock is cut into small blocks by numerous unsystematically arranged joint planes. This, however, served as no guide, for the granitite is occasionally cut by equally frequent joints.

Petrographically, the rock is composed of plagioclase feldspar, with much biotite and hornblende. Quartz is often very abundant, orthoclase feldspar, apatite, and zircon occur occasionally.

It is difficult to determine which of these two rocks is the older. The region is so drift-covered that the contact can not be seen; but wherever it is approached the granitite becomes markedly porphyritic; in some places, however, as for instance on the hill called "The Poles," in Gloucester, the diorite exhibits the same phenomenon. The contact effects are not uniformly well marked, which may be explained by the supposition that at the time of the injection of one of the masses the other was still very much heated. No dike of granitite has been found cutting the diorite, nor does this rock, so far


40'
Twopenny Loaf
Coffins Beach
West Gloucester
Little River
BOSTON & MAINE
BRANCH
West Gloucester Station
GLOUCESTER
35'
Magnolia
Little Cove
Crescent Beach
Magnolia Point

GEOLOGIC MAP
OF
CAPE ANN
MASS.

Showing distribution of Glacial Scratches etc.

by

N. S. SHALER.

Glacial Scratches. Movement of Marine detritus. Marine-Marshes. Fresh water marshes. Fresh water Lakes.

Scale 1/62,500

0 1/2 1 2 3 4 5 Miles

Contour Interval 20 feet.

Halibut Point
Folly Point
Sunset Hill
Hoop Pole Cove
Andrews Point
Ocean View
Lanesville
Pigeon Cove
Pigeon Hill
Davis Neck
Hodgkins Cove
Bay View
SANDY BAY
SQUAM LIGHT
ANNISQUAM HARBOR
Twopenny Loaf
Coffins Beach
Annisquam
Lobster Cove
Goose Cove
Poles Hill
Rockport
Gap Head
The Gap
Gap Cove
Straitsmouth Island
Whale Cove
Flat Point
Lobllolly Cove
Loblolly Head
Emersons Point
Cape Hedge
Thatchers Island
Cape Pond
Wheelers Point
Jones River
Pearces Island
Squam River
Riverdale
Wall River
Long Beach
Milk Island
Ralcut Hill
Briar Neck
Salt Island
Salt Island Ledge
Little Good Harbor Beach
Bass Rocks
Rusts Id.
Wolf Hill
West Gloucester
Little River
BOSTON AND MAINE RAILROAD
GLOUCESTER BRANCH
Gloucester
West Gloucester Station
Pavilion Beach
Five Pound I.
East Gloucester
Freshwater Cove Village
Rocky Neck
Ten Pound Island
High Pebble Beach
GLOUCESTER HARBOR
Eastern Point
Miles Pond
Braces Cove
Bemo Ledge
EASTERN POINT LIGHT
Muscle Point
Normans Woe Rock
Magnolia
Normans Woe
Crescent Beach
Kettle Cove
Magnolia Point

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as observed, send tongues into the granitite. In several places, notably on the road to Coffin's Beach, and in the vicinity of Bond's Hill, on the west side of Squam River, opposite the city of Gloucester, the diorite is in such a position as to indicate that it is included in the granitite. Owing to the abundance of drift, this point in any of these localities can not be definitely settled. The first impression was that we had here a great dike of diorite cutting the granitite; but every indication in the field points to the opposite conclusion, namely, that the granitite has burst up around this diorite, leaving it as an included mass.

The mass of diorite is apparently of an irregularly circular form, having its center at about the middle of the Annisquam Reach on Rust's Island. On all sides where the rocks outcrop, it is surrounded by granitite, the two entrances of the Reach being the only places where it could possibly have cut the granitite. These entrances are narrow and are bounded on either side by granitite which is not porphyritic, which facts almost exclude the hypothesis that the diorite has cut the granitite. The porphyritic character of the granitite in many places is remarkably well developed; but nowhere better than at West Gloucester, near the Russian Cement Company's factory. The granite porphyry at this point has fine, large porphyritic crystals of quartz and feldspar in a ground mass composed mainly of the same minerals. It is very finely jointed, as may be seen in the picture of the post-glacial talus. (See Pl. L.) The approach of the diorite and granite is generally, though not invariably, marked by a distinct drift-filled valley. The granite as it approaches the contact is very much broken, and, even when not porphyritic, quite different from the typical Cape Ann granite.

The abundance of hornblende, the character of the feldspar, and the general absence of quartz, all render this rock open to the attack of the elements. This weakness is enhanced by the character of the jointing, both in this diorite and in the surrounding granite.

Some petrographic study has been given to the phenomena of inclusions, veins, segregations, dikes, decomposition and rift as observed in the granite of this island. Veins and segregations are both quite commonly found. In the Rockport quarry, pockets exist in the granite containing quartz and feldspar, intergrown to form the so-called graphic granite. In connection with these, are large nodules of smoky and milky quartz, masses of green feldspar, and small segregations of magnetite, frequently containing on their edges small, perfect prisms of zircon, terminated by pyramids with convex faces. Fluorite and danalite also occur in these veins in considerable masses. On the sea shore, little pockets and veins of graphic granite, blue quartz, feldspar, hornblende, and magnetite are often found, though they are by no means as common as in other regions on the New England coast.

Basic segregations, the "black patches" of the quarrymen, are met with in all the quarries. These are irregular, bluish patches, composed of feldspar and the more basic of the granitic constituents fading quite gradually into the true granitite. These patches represent the remnants of original segregations of the more basic elements from the granitic magma, before the final cooling of the mass. The variations in the hue, from a light blue to a very dark shade of the same color, depends upon the abundance of hornblende and magnetite which occur in fine grains scattered through the feldspar and quartz ground mass. In the slides, these basic segregations show the ordinary granite minerals in very fine grains, and in different proportions from that of the true granitite. Both orthoclase and plagioclase feldspar occur, the latter being rare; fine grained quartz is very abundant; hornblende and magnetite are common; and there is some biotite. The microperthite intergrowth of feldspar is extremely well shown, and Carlsbad twins are found everywhere. The effect of strain is shown in all the quartz grains of sufficient size.

True inclusions of other rocks are not commonly met with in the granitic material. Near the contact of the granitite with the diorite in the West Gloucester district, apparent inclusions of diorite are common. In other parts of the region undoubted inclusions of dioritic and gneissoid rocks are found. Instances of the latter kind of inclusions were noticed on Davis' Neck, and at various other points along the Bay View and Lanesville shore. From the large number of included fragments, on this northwest shore of the island, one might be led to suspect that the locality is near the contact of the granitite with gneiss which may occupy the bed of Ipswich Bay.

Wherever any area of an acre or more of rock is bared by the waves, or by the quarryman's work, we find dike rocks cutting the granite. As before described, over three hundred and fifty dikes have been observed, mainly upon the sea shore line. The dikes, being more easily eroded than the granitite, seldom outcrop in the interior region. There can be no doubt that they are as abundant here as on the sea shore and their positions are often suggested by narrow drift-filled chasms in the granitite.

No thorough petrographic study has been made of any of these dikes; but a few of the more interesting ones have been subjected to a cursory microscopic examination. In general, it may be said that the dike rocks are either diabase or quartz porphyry, and these two general divisions only have been adopted in the accompanying map of the bed rock. Numerous subdivisions might be made upon the basis of the ground mass or special variations of mineral composition, but no attempt has been made to do so.

Dikes numbered on the map as follows have been found by a microscopic examination to be diabase: 5, 9, 57, 61, 91, 131, 150, 175, 201,

Twopenny Loaf
Coffins Beach
West Gloucester
Little River
BOSTON & GLOUCESTER BRANCH
West Gloucester Station
Magnolia
Crescent Beach
Magnolia Point
Ettle Cove

GEOLOGIC MAP OF CAPE ANN MASS.

Showing superficial Deposits

by

N. S. SHALER.

Halibut Point
Folly Point
Sunset Hill
Hoop Pole Cove
Andrews Point
Ocean View
Lanesville
Pigeon Cove
Pigeon Hill
Davis Neck
Bay View
SANDY BAY
SQUAM LIGHT
ANNISQUAM HARBOR
Twopenny Loaf
Coffins Beach
Annisquam
Poles Hill
Rockport
Gap Head
Straitsmouth Island
Whale Cove
Flat Point
Loblolly Cove
Loblolly Head
Emersons Point
Cape Hedge
Thatchers Island
Milk Island
Wheelers Point
Pearces Island
Hirecdale
Capel Pond
Railcut Hill
Briar Neck
Salt Island
Salt Island Ledge
Little Good Harbor Beach
Bass Rocks
West Gloucester
Gloucester
BOSTON AND MAINE RAILROAD
GLOUCESTER BRANCH
West Gloucester Station
Pavilion Beach
Five Pound I.
East Gloucester
Freshwater Cove Village
Rocky Neck
Ten Pound Island
High Pebble Beach
GLOUCESTER HARBOR
Eastern Point
Miles Pond
Braces Cove
Bemo Ledge
EASTERN POINT LIGHT
Muscle Point
Normans Woe Rock
Normans Woe
Magnolia
Crescent Beach
Magnolia Point
Kettle Cove
Long Beach

Sand Beach.
Blown Sand.
Stratified drift kame and terrace.
Ordinary till.
Moraine.
Drumlin.
Bands of excessively rocky moraine.
Granite and other bed-rocks not covered by drift.

Scale 1/62,500

0 1/2 1 2 3 4 5 Miles

Contour Interval 20 feet.

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217, 229, 264, 276, 277, and 299. They have the ordinary diabase composition, most being porphyritic; some holocrystalline; others cryptocrystalline. No signs of glass are present though the contact is often very fine grained and dense and may be composed of devitrification products. Lath-shaped plagioclase crystals are always present both as porphyritic crystals when the rock is porphyritic and in the ground mass. It is sometimes very clear and glassy; but more often somewhat decomposed. In some cases complete sausaurization results. Signs of paramorphism are not wanting. Brown and very pleochroic biotite is common as a primary constituent and also as a secondary product. It contains the usual diabase inclusions and alters readily to chlorite. Fine crystals of augite occur in the porphyrites, in some cases being pleochroic, but generally clear and colorless or pale green. The ground mass is frequently one-half augite. It decomposes readily to chlorite, green hornblende, magnetite, etc., until often no trace of it is left in the rock. This is the case in dikes Nos. 91 and 299. Muscovite, calcite, magnetite, iron pyrite, apatite, epidote and other products of decomposition are common in the slides made from all these dikes. In one case olivine was also present. No. 175 is a large dike of metamorphosed diabase porphyry 18 feet in width and extending several miles in Rockport and Pigeon Cove. It has extremely large plagioclase feldspar crystals several inches in length, often very much decomposed. The ground mass is holocrystalline, made up of very much decomposed lath-shaped plagioclase, hornblende, chlorite and magnetite mainly. The augite has almost completely disappeared in some cases, remaining simply as a core within a mass of green hornblende.

Only one dike, No. 237, has been studied, which can be called diorite, although many are so metamorphosed that no augite is present. This No. 237 is a very interesting dike of diorite porphyrite. It is very much faulted, and occurs at various points along the entire Lanesville shore. It has large crystals of feldspar, several inches in length, finely striated and very iridescent, hence probably labradorite. The feldspar is extremely decomposed to kaolin, muscovite, calcite, etc. Secondary green hornblende and biotite occur along the cracks in the feldspar and in bunches throughout the mass.[1] The rock is undoubtedly very much altered from its original state, and a careful study of it will be made and reported upon later.

There is considerable quartz and feldspar porphyry among the Cape Ann dikes. Nos. 3, 53, 127, 135, 147, 182, and 184 are of this character. No. 3 has porphyritic crystals of plagioclase and orthoclase feldspar and rounded quartz considerably resorbed. The ground mass is micrographitic, mainly quartz, feldspar, and hornblende, mostly the very pleochroic blue variety glaucophane, which gives a decided blue color to the rock. No. 53 has porphyritic crystals of feldspar with distinct outlines, but somewhat decomposed. The

ground mass is a confused aggregation of vesicular needles of brown hornblende, with clear spaces quite granophyric. This appearance may be primary, but it gives one the impression of felsite with a glassy or microfelsitic base altered to this condition.

Nos. 127 and 135 are more typical quartz and feldspar porphyries. They occur as faulted and very irregular dikes, in some places, as at 127, looking like chimneys cutting the granite. Wherever a contact has been observed between the diabase dikes and quartz porphyries, the latter are found to be the older, and their ragged outline would indicate that they cut the granite before the joint planes were formed, for they never follow any system of joints and are often faulted along the line of joint planes. These dikes have the usual character of quartz porphyry. Embayed porphyritic crystals of quartz and feldspar exist in a ground mass of quartz, feldspar, hornblende, and biotite. In the center the ground mass is quite holocrystalline, but at the contact it becomes cryptocrystalline. No glass or microfelsite is found, although the structure leads one to suspect that these conditions once existed, and that the present structure is the result of devitrification.

Nos. 182 and 184 are narrow schistose dikes, apparently very much altered. They are fine grained, and composed of a mass of undecomposed feldspar, quartz, and blue hornblende—glaucophane. The rock shows signs of flow structure, and might be a gneissoid rock as well as a feldspar porphyry, but in places it has indistinct porphyritic feldspar crystals. The field evidence shows that they are dike rocks and the crystals look like porphyritic feldspars rather than crystals of secondary origin. Dike 135 has the quartz crystals very much faulted, and the cracks filled with the ground mass. In one place the graphic granite structure shows. The extensive cracking of the quartz grains seems to show that it has undergone some of the movements which have jointed the granite. The joints, too, are not all such as can be explained by cooling alone.

No. 147, on Thatcher's Island, is an interesting dike of quartz porphyry, which shows a beautiful spherulitic structure. It has a cryptocrystalline ground mass of quartz and feldspar with porphyritic crystals of the same. A more thorough petrographic study will be made of some of these dikes, the object in this report being simply to indicate their general character.

INFLUENCE OF GEOLOGICAL STRUCTURE UPON THE HEALTH OF THE DISTRICT.

Although the general position of Cape Ann should be favorable to the health of its inhabitants, the vital and sanitary statistics show that the area suffers from certain classes of maladies, known as zymotic diseases. It is probable that these evils are caused in part at least by the failure to recognize the important fact that the soil of

40'
Twopenny Loaf
Coffins Beach
West Gloucester
Little River
BOSTO
BRANCH
GLOUCESTER
West Gloucester Station
35'
Magnolia
Kettle Cove
Crescent Beach
Magnolia Point

GEOLOGIC MAP OF CAPE ANN MASS.

Showing distribution of Dikes etc.

by

N. S. SHALER.

Granite. Diorite. Diabase dikes. Quartz porphyry dikes.

Scale 1/62,500

0 ½ 1 2 3 4 5 Miles

Contour Interval 20 feet.

LIT. A. HOEN & CO., BALTO.

this peninsula is of a peculiar character. Almost all the other coast towns of New England are in the main underlain by permeable drift, kames, or other detritus, containing little or no clay. As will be seen from the map, nearly the whole of Gloucester and Rockport rest upon till. Even where there are materials affording ready passage to ground water, the bed rocks are often very near the surface and thus the sewage is unable to penetrate to any great depth and becomes mixed with the water of the wells. At least three-fourths of the sources of domestic water supply on the Cape from wells and springs are liable to contamination. I know no other equal area in Massachusetts where the sources of potable waters are in general so objectionable as in these two towns of Gloucester and Rockport. Recently the city of Gloucester has provided itself with a system of water supply drawn from a tolerably satisfactory source west of Annisquam River; but a large part of the water in that city is still obtained from wells, and the villages of Rockport, Pigeon Cove, Lanesville, Bay View, and Annisquam are dependent on such sources of supply.

It will be easy to remedy these difficulties at a relatively small cost. The unsettled region of the great moraines, the section commonly known as "Dogtown Commons," contains an area of several square miles of land which at present has very little value. A thousand acres of this land in the center of the island should be reserved for water supply. This morainal matter is so permeable to water that wells of no great depth placed in the center of such a reservation would afford a sufficiency to supply all the settlements along the coast line. This water would be obtained at such a height that the costs of pumping would be small. The land for such a source of supply could probably be obtained at the present time at a small cost, and the maximum distance from the source to the furthest of the shore settlements would not exceed three miles. An incidental advantage arising from such a reservation would be found in the fact that it might in time be made a park of value to all the settlements on this island.